ELECTRIC WELI

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ETHAN VIALL

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PREFACE

Few fields afford a greater opportunity for study to the mechanic, the student, or the engineer, than that of electric welding. Arc welding, with its practical, every-day, shop applications for repair and manufacture, is in some respects crowding closely into the field in which the gas-torch has seemed supreme. With the development of mechanical devices for the control of the arc, the range of application to production work has greatly increased.

Resistance welding presents in its various branches some of the most interesting scientific and mechanical problems to be found anywhere. Spot-welding—butt-welding—line-welding—all occupy a particular place in our manufacturing plants today, and new uses are being constantly found.

In the gathering and arranging of the material used in this book, particular care has been taken to classify and place various subjects together as far as possible. This is not only convenient for reference purposes, but enables the reader to easily compare different makes and types of apparatus. In most cases, the name of the maker of each piece of apparatus is mentioned in the description in order to save the time of those seeking information.

No time or pains have been spared in the endeavor to make this the most comprehensive book on electric welding equipment and practice, ever published. Every possible source of information known to the long-experienced editor has been drawn upon and properly credited.

It is hoped that this book will prove a permanent record of electric welding as it is today, and also be an inspiration and source of information for those engaged in practice, research or development.

Ethan Viall.

New York City,
November, 1920.

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ELECTRIC WELDING

CHAPTER I

ELECTRIC WELDING—HISTORICAL

All electric welding may be divided into two general classes —arc welding and resistance welding. In each class there are a number of ways of obtaining the desired results. Arc welding is the older process, and appears to have been first used by de Meritens in 1881 for uniting parts of storage batteries. He connected the work to the positive pole of a current supply capable of maintaining an arc. The other pole was connected to a carbon rod. An arc was struck by touching the carbon rod to the work and withdrawing it slightly. The heat generated fused the metal parts together, the arc being applied in a way similar to that of the flame of the modern gas torch.

Of the several methods of arc welding, there are the Zerner, the Bernardos, the Slavianoff and the Strohmenger-Slaughter processes, as well as some modifications of them. The different methods are named after the men generally credited with being responsible for their development. The LaGrange-Hoho process is not a welding process at all, as it is merely a method of heating metal which is then welded by hammering, as in blacksmith work. It is sometimes called the "water-pail forge."

The Zerner process employs two carbon rods fastened in a holder so that their ends converge like a V, as shown in Fig. 1. An arc is drawn between the converging ends and this arc is caused to impinge on the work by means of a powerful electromagnet. The flame acts in such a manner that this process is commonly known as the electric blowpipe method. The Zerner process is so complicated and requires so much skill that it is practically useless. A modification of the Zerner process, known

as the "voltex process," uses carbon rods containing a percentage of metallic oxide which is converted into me vapor. This vapor increases the size of the arc and to extent prevents the excessive carbonizing of the work. process, however, is about as impractical for general use a other.

The Bernardos process employs a single carbon or gra;

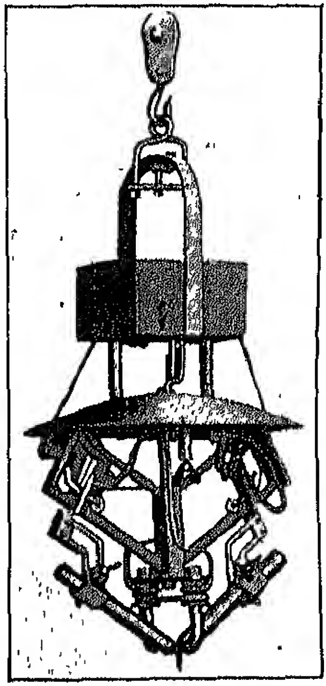


Fig. 1.—The Zerner Electric "Blow-Pipe."

rod and the arc is drawn between this rod and the work. sketch of the original apparatus is shown in Fig. 2. is commonly called the carbon-electrode process. In using method it is considered advisable to connect the carbon to negative side and the work to the positive. This prevents carbon of the rod from being carried into the metal and a s weld is produced.

In the Slavianoff process a metal electrode is used ins

of a carbon. This process is known as the metallic-electrode process.

The Strohmenger-Slaughter, or covered electrode, process is similar to the Slavianoff except that a coated metallic elec-

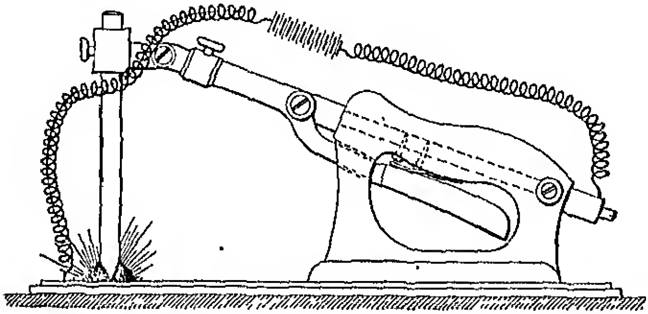


FIG. 2.—Original Bernardos Carbon Electrode Apparatus.

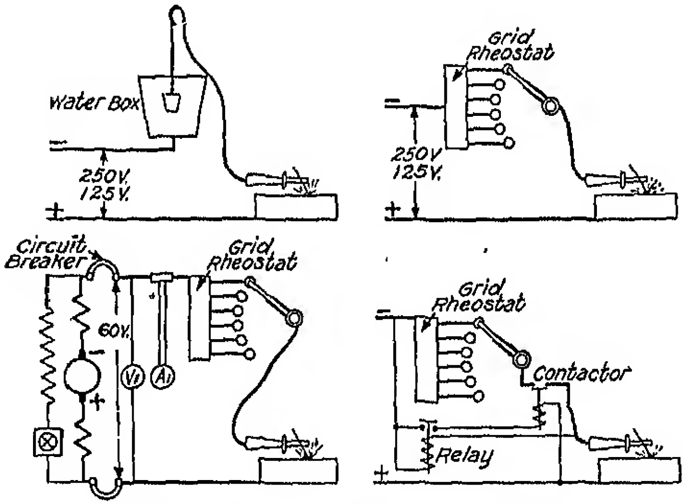


FIG. 3.—Arc Welding Circuits as First Used.

trode is used. In this process either direct or alternating current may be used.

Some of the early methods of connecting up for arc welding are shown in Fig. 3.

The LaGrange-Hoho heating process makes use of a wooden tank filled with some electrolyte, such as a solution of sodium

or potassium carbonate. A plate connected to the positiv is immersed in the liquid and the work to be heated is con to the negative wire. The work is then immersed in the l When the piece has reached a welding temperature it is re and the weld performed by means of a hammer and anvil

Resistance Welding.—The idea of joining metals by r of an electric current, known as the resistance or incand process, was conceived by Elihu Thomson some time in

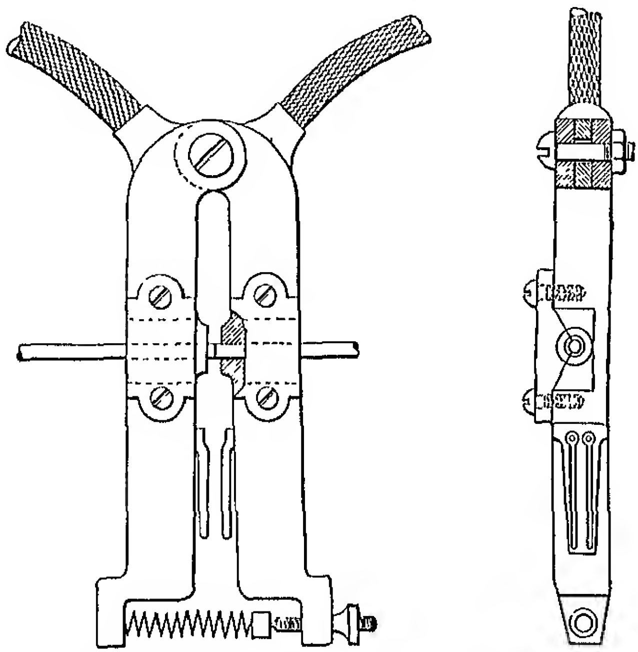


FIG. 4.—First Practical Electric Butt Welding Device, Patente by Elihu Thomson, Aug. 10, 1886.

Little was done with the idea from a practical standpoin several years. Between 1883 and 1885 he developed and an experimental machine. A larger machine was built in He obtained his first patent on a device for electric wel Aug. 10, 1886. The general outline of this first device is sl in Fig. 4. The first experiments were mostly confined to is now known as butt welding, and it was soon found tha jaws used to hold the parts heated excessively. To remedy water-cooled clamping jaws were developed.

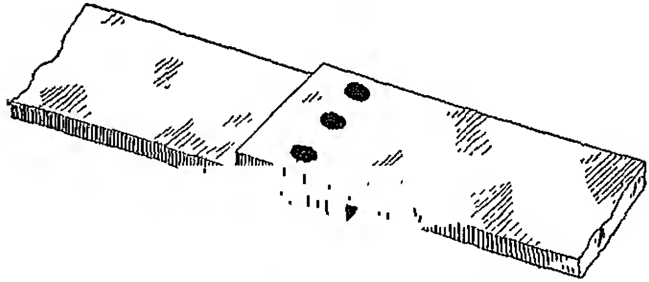


FIG. 5.—Plates "Spot Welded" by Carbon Arc.

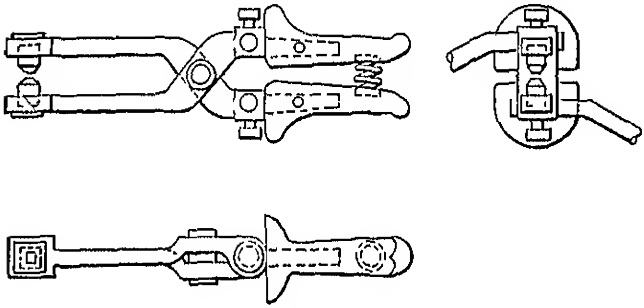


FIG. 6.—The DeBenardo Carbon Electrode Spot Welding Apparatus.

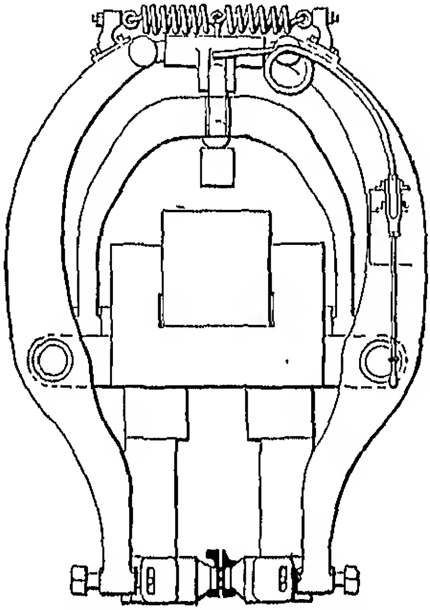


FIG. 7.—The Kleinschmidt Apparatus, Using Copper Electrodes.

Closely following the butt welding came other applications of the resistance process, such as spot, point or projection, ridge and seam welding. Percussive welding, which is a form of resistance welding, was developed about 1905. Since spot welding is such an important factor in the manufacturing field today

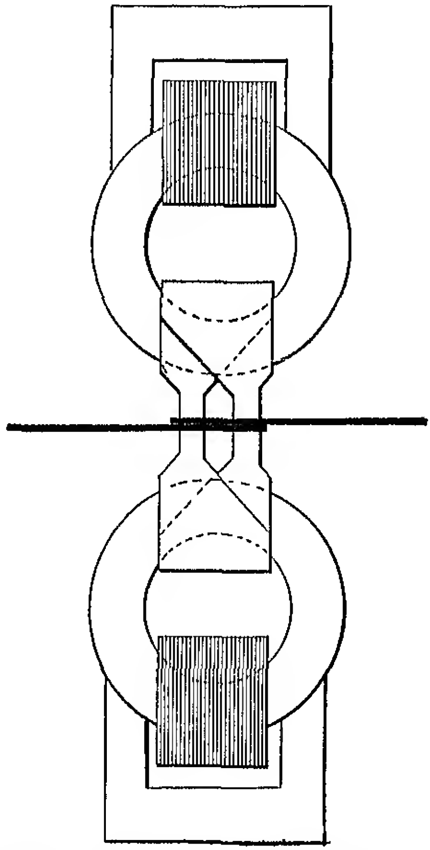


FIG. 8.—Bouchayer's Spot Welding Machine, Using Duplex Copper Electrodes.

the evolution of this process, as indicated by the more prominent patents, will be of considerable interest: Fig 5 shows plates spot welded together by means of the carbon arc. This was patented by DeBenardo, May 17, 1887, Pat. No. 363,320. The claims cover a weld made at points only. The darkened places indicate

where the welds were made. Fig. 6 shows the apparatus made by DeBenardo for making "spot welds," as they are known today. He patented this in Germany, Jan. 21, 1888. Carbon electrodes were used. This patent was probably the first to cover the process of welding under pressure and also for passing the current through the sheets being welded. The German patent number was 46,776—49.

The apparatus shown in Fig. 7 is known as the Kleinschmidt patent, No. 616,463, issued Dec. 20, 1898. The patent claims cover the first use of pointed copper electrodes and raised sections, or projections, on the work in order to localize the flow of the current at the point where the weld was to be effected.

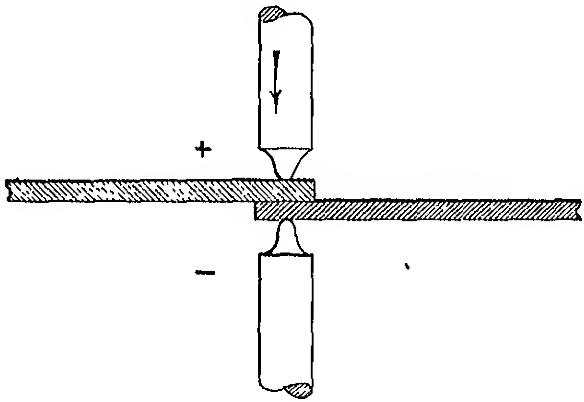


FIG. 9.—Principle of the Harmatta Process, Using Copper Electrodes.

Considerable pressure was also applied to the electrodes and work by mechanical means.

Fig. 8 shows diagrammatically Bouchayer's spot welding machine, patented in France, March 13, 1903, No. 330,200. He used two transformers, one on each side of the work. Duplex copper electrodes were used, and if the transformers were connected parallel one spot weld would be made at each operation. If the transformers were connected in series two spot welds would be made.

Fig. 9 illustrates the principle of the Harmatta patent, No. 1,046,066, issued Dec. 3, 1912. This is practically the same as the DeBenardo patent, No. 46,776—49, except that copper elec-

trodes are used. However, it is under the Harmatta patent that a majority of the spot welding machines in use today are made.

Fig. 10 illustrates the principle on which the Taylor patent is founded. This patent was issued Oct. 16, 1917, No. 1,243,004. It covers the use of two currents which are caused to cross the path of each other in a diagonal direction, concentrating the heating effects at the place of intersection.

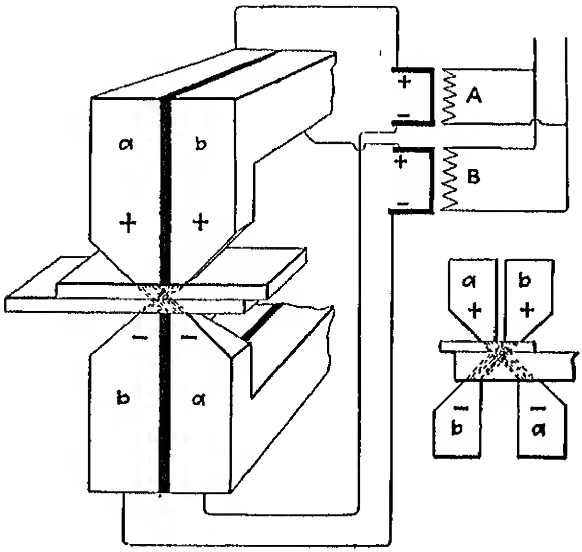


Fig. 10.—The Taylor Cross-Current Spot Welding Method.

From the foregoing it will be seen that spot welds, as this term is now understood, can be produced in a number of ways, none of which methods are identical. As a matter of fact, spot welds can be produced by means of the gas torch or by the blacksmith forge and anvil, although these methods would not be economical.

CHAPTER II

ARC WELDING EQUIPMENT

Electric Arc Welding is the transformation of electrical energy into heat through the medium of an arc for the purpose of melting and fusing together two metals, allowing them to melt, unite, and then cool. The fusion is accomplished entirely without pressure. The heat is produced by the passage of an electric current from one conductor to another through air which is a poor conductor of electricity, and offers a high resistance to its passage. The heat of the arc is the hottest flame that is obtainable, having a temperature estimated to be between 3,500 and 4,000 deg. C. (6,332 to 7,232 deg. F.).

The metal to be welded is made one terminal of the circuit, the other terminal being the electrode. By bringing the electrode into contact with the metal and instantly withdrawing it a short distance, an arc is established between the two. Through the medium of the heat thus produced, metal may be entirely melted away or cut, added to or built up, or fused to another piece of metal as desired. A particularly advantageous feature of the electric arc weld is afforded through the concentration of this intense heat in a small area, enabling it to be applied just where it is needed.

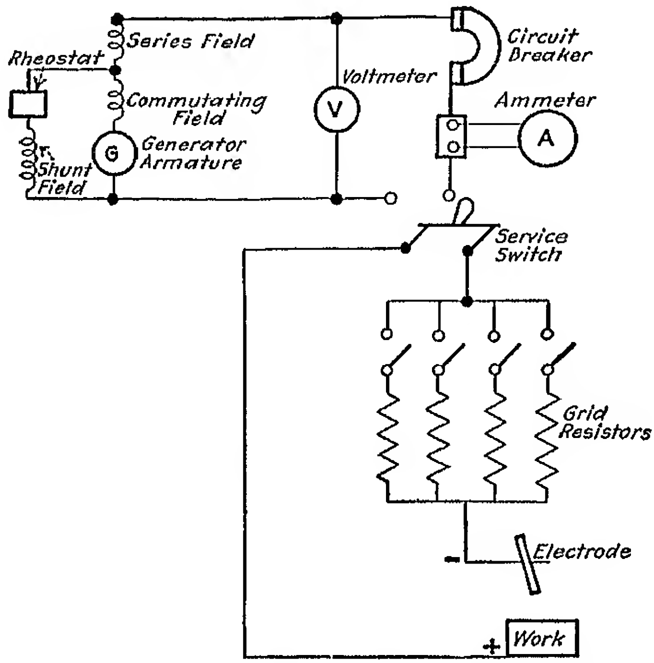
Direct-current is now more generally used for arc welding than alternating-current.

When using direct-current, the metal to be welded is made the positive terminal of the circuit, and the electrode is made the negative terminal.

Regarding alternating-current it is obvious that an equal amount of heat will be developed at the work and at the electrode, while with direct-current welding we have considerably more heat developed at the positive terminal. Also in arc welding the negative electrode determines the character of the arc, which permits of making additions to the weld in a way that is

not possible with alternating-current. Inasmuch as the work always has considerably greater heat-absorbing capacity than the electrode, it would seem only reasonable that the direct-current arc is inherently better suited for this work.

Two systems of electric arc welding, based on the type of electrode employed, are in general use, known as the carbon (or graphite) and the metallic electrode processes. The latter



Courtesy of the Westinghouse Co.

Fig. 11.—Simple Schematic Welding Circuit.

process is also sub-divided into those using the bare and the covered metallic electrodes.

A simple schematic layout for an arc-welding outfit is shown in Fig. 11.

The Carbon Electrode Process.—In this process, the negative terminal or electrode is a carbon pencil from 6 to 12 in. in length and from $\frac{1}{4}$ to $1\frac{1}{2}$ in. in diameter. This was the original process devised by Bernardos and has been in more or less general

use for more than thirty years. The metal is made the positive terminal as in the metallic electrode process in order that the greater heat developed in this terminal may be applied just where it is needed. Also, if the carbon were positive, the tendency would be for the carbon particles to flow into the weld and thereby make it hard and more difficult to machine.

The current used in this process is usually between 300 and 450 amp. For some special applications as high as from 600 to 800 may be required, especially if considerable speed is desired. The arc supplies the heat and the filler metal must be fed into the weld by hand from a metallic bar.

The class of work to which the carbon process may be applied includes cutting or melting of metals, repairing broken parts and building up materials, but it is not especially adapted to work where strength is of prime importance unless the operator is trained in the use of the carbon electrode. It is not practical to weld with it overhead or on a vertical surface but there are many classes of work which can be profitably done by this process. It can be used very advantageously for improving the finished surface of welds made by metal electrodes. The carbon electrode process is very often useful for cutting cast iron and non-ferrous metals, and for filling up blowholes.

The Metallic Electrode Process.—In the metallic electrode process, a metal rod or pencil is made the negative terminal, and the metal to be welded becomes the positive terminal.

When the arc is drawn, the metal rod melts at the end and is automatically deposited in a molten state in the hottest portion of the weld surface. Since the filler is carried directly to the weld, this process is particularly well adapted to work on vertical surfaces and to overhead work.

If the proper length of arc is uniformly maintained on clean work, the voltage across the arc will never greatly exceed 22 volts for bare electrodes and 35 volts for coated electrodes. The arc length will vary to a certain degree however, owing to the physical impossibility of an operator being able to hold the electrode at an absolutely uniform distance from the metal throughout the time required to make the weld.

It is very essential that the surfaces be absolutely clean and free from oxides and dirt, as any foreign matter present will materially affect the success of the weld.

When using a metallic electrode, the arc which is formed by withdrawing it from the work, consists of a highly luminous central core of iron vapor surrounded by a flame composed largely of oxide vapors. At the temperature prevailing in the arc stream and at the electrode terminals, chemical combinations occur instantaneously between the vaporized metals and the atmospheric gases. These reactions continue until a flame of incandescent gaseous compounds is formed which completely envelopes the arc core. However, drafts created by the high temperature of the vapors and by local air currents tend to remove this protecting screen as fast as it is formed, making it necessary for the welder to manipulate the electrode so that the maximum protective flame for both arc stream and electrode deposit is continuously secured. This can be obtained automatically by the maintenance of a short arc and the proper inclination of the electrode towards the work in order to compensate for draft currents.

Selection of Electrodes.—The use of a metallic electrode for arc welding has proved more satisfactory than the use of a carbon or graphite electrode which necessitates feeding the new metal or filler into the arc by means of a rod or wire. The chief reason for this is that, when the metallic electrode process is used, the end of the electrode is melted and the molten metal is carried through the arc to be deposited on the material being welded at the point where the material is in a molten state produced by the heat of the arc. Thus a perfect union or fusion is produced with the newly deposited metal.

Wire for metallic arc welding must be of uniform, homogeneous structure, free from segregation, oxides, pipes, seams, etc. The commercial weldability of electrodes should be determined by means of tests performed by an experienced operator, who can ascertain whether the wire flows smoothly and evenly through the arc without any detrimental phenomena.

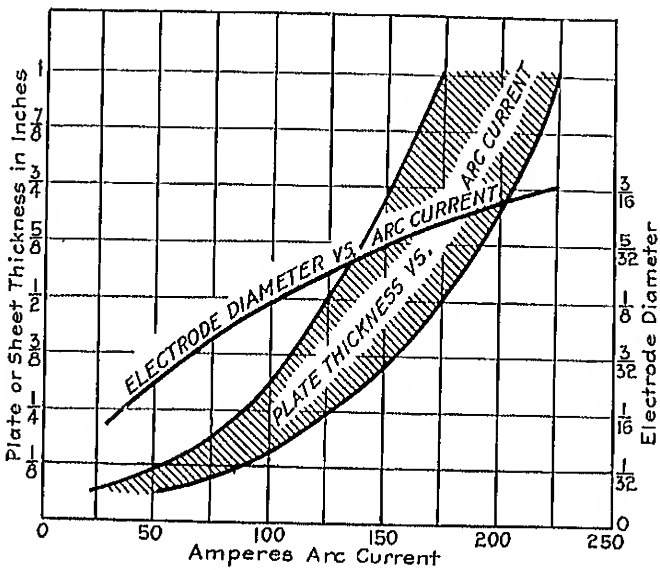
The following table indicates the maximum range of the chemical composition of bare electrodes for welding mild steel:

Carbon trace up to	0.25%
Manganese trace up to	0.99%
Phosphorous not to exceed	0.05%
Sulphur not to exceed	0.05%
Silicon not to exceed	0.08%

The composition of the mild steel electrodes, commonly used, is around 0.18 per cent carbon, and manganese not exceeding 0.05 per cent, with only a trace of phosphorus, sulphur and silicon.

The size, in diameter, ordinarily required will be $^1/_8$ in., $^5/_{32}$ in., and $^3/_{16}$ in. and only occasionally the $^3/_{32}$ in.

These electrodes are furnished by a number of firms, among whom are John A. Roebling's Sons Co., Trenton, N. J.; American Rolling Mills Co., Middletown, Ohio; American Steel and Wire



Courtesy of the Westinghouse Co.

FIG. 12.—Relation of Approximate Arc Currents and Electrode Diameters.

Co., Pittsburgh; Ferride Electric Welding Wire Co., New York City; Page Woven Wire Co., Monessen, Pa.; John Potts Co., Philadelphia.

A coated electrode is one which has had a coating of some kind applied to its surface for the purpose of totally or partially excluding the atmosphere from the metal while in a molten state when passing through the arc and after it has been deposited.

The proper size of electrode may be determined from Fig. 12 from which it will be seen that the class of work and current used are both factors determining the size of the electrode for

welding steel plates of various thicknesses. To find the diameter of the metallic electrode required, select, for example, a three-eighths plate, and follow horizontally to the "Thickness of the Plate Curve." The vertical line through this intersection represents about 110 amp. as the most suitable current to be used with this size of plate. Then follow this vertical line to its intersection with the "Diameter of Electrode" curve which locates a horizontal line representing approximately an electrode $^5/_{32}$ in. in diameter. In a similar manner, a $^1/_2$-in. plate requires about 125 amp. and a $^5/_{32}$-in. electrode.

The amount of current to be used is dependent on the thickness of the plate to be welded when this value is ¾ in. or less. Average values for welding mild steel plates with direct current are indicated by the curve referred to above in connection with the selection of the electrode of proper size. These data are also shown in Table I.

TABLE I.—APPROXIMATE CURRENT VALUES FOR PLATES OF DIFFERENT THICKNESS

Plate Thickness in Inches	Current in Amperes	Electrode Diameter in Inches
1/16	20 to 50	1/16
1/8	50 to 85	3/32
3/16	75 to 110	1/8
1/4	90 to 125	1/8
3/8	110 to 150	5/32
1/2	125 to 170	5/32
5/8	140 to 185	5/32
3/4	150 to 200	3/16
7/8	165 to 215	3/16
1	175 to 225	3/16

It should be borne in mind, however, that these values are only approximate as the amount of current to be used is dependent on the temperature of the plate and also upon the type of joint. For example, when making a lap weld between two ½-in. steel plates at ordinary air temperature of about 65 deg. F. it has been found that the extra good results were obtained by using a current of about 225 amp. and a $^3/_{16}$-in. diameter electrode. The explanation for the high current permissible is the tremendous heat storage and dissipation capacity of the lapped plates which makes the combination practically

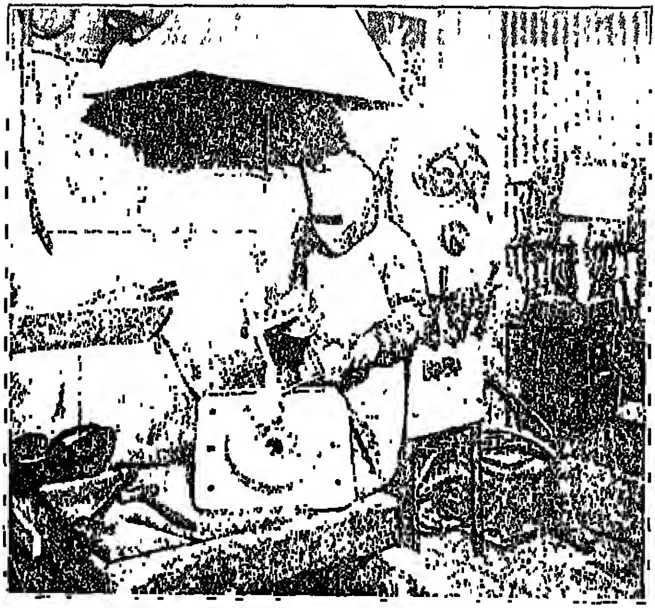


FIG. 13.—Carbon-Arc Welding, Using King Mask.

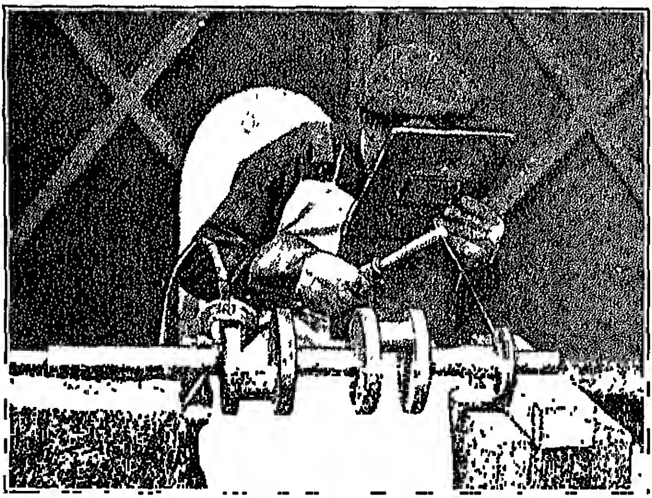


FIG. 14.—Metallic-Arc Welding, Using a Hand Shield.

equivalent to that of a butt weld of two 1-in. plates. For that reason the above values will be very greatly increased in the case of lap welds which require practically twice the amount of current taken by the butt welds.

When the proper current value is used there will be a crater,

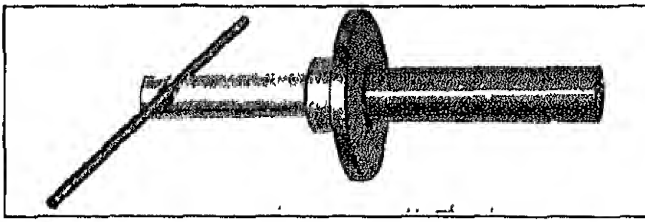


FIG. 15.—Simple Form of Electrode Holder.

or depression, formed when the arc is interrupted. This shows that the newly deposited metal is penetrating or "biting into" the work.

The difference between the carbon and the metallic electrode processes can be seen in Figs. 13 and 14. In Fig. 13 the welder

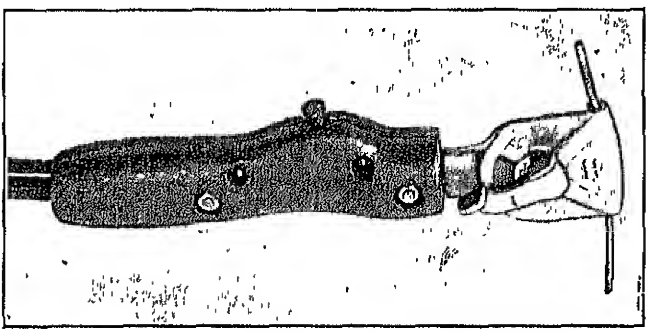


FIG. 16.—Special Make of Electrode Holder.

is using a carbon electrode and feeding metal into the weld from a metal rod held in his left hand. In Fig. 14 the metal rod is held in a special holder and not only carries the current but metal from it is deposited on the work.

Electrode holders should be simple, mechanically strong, and so designed as to hold the electrode firmly. It should be prac-

tically impossible to burn or damage the holder by accidental contact so that it will not work. Small, flimsy or light projecting parts are almost sure to be broken off or bent. Fig. 15 shows one of these holders that answers the requirements. However, any of the companies selling arc welding apparatus will be able to supply dependable holders.

A holder made by the Arc Welding Machine Co., New York, is shown in Fig. 16 and in detail in Fig. 17. The metal rod is clamped in by means of an eccentric segment operated by a thumb lever. If the rod should freeze to the work it will not pull out of the holder, but will be gripped all the tighter. The

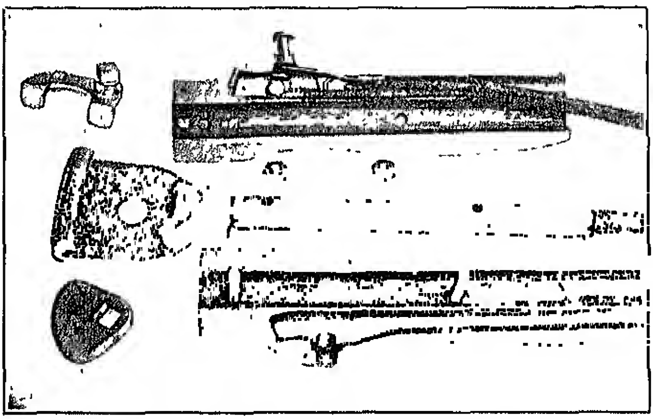


Fig. 17.—Details of Special Electrode Holder.

welding current enters at the rear end of the composition shank, passes along the shank to the head of the tool, and from there directly into the electrode. It will be noted that there are no joints in this tool except where the cable is soldered into the shank. There is a relatively large contact surface between the electrode and the holding head, which precludes any possible heating at this point. The trigger is intended for remote control employed with the closed circuit system. Whenever this holder is used on other systems, the trigger is omitted.

Cable.—For arc welding service the cables leading to the electrode holder should be very flexible in order to allow the operator full control of the arc.

The following sizes of cable have been found by the General

Electric Co. suitable for this service, due account being taken of the intermittent character of the work.

It is extra flexible stranded dynamo cable, insulated for 75-v. circuit, with varnished cambric insulation, covered with weather-proof braid.

Amperes	Size of Cable	Circular Mills
Up to 200	225/24	90,000
Over 200 Up to 500	375/24	150,000
Over 500 Up to 1,000	650/24	260,000

It will be noted in Figs. 13 and 14, that two different ways of protecting the eyes are shown. One man has a helmet and

FIG. 18.—King Face Masks With and Without Side Screens.

the other uses a shield held in the hand. Conditions under which the welders work, and their personal preferences, largely dictate which type is to be used. However, no welder should ever attempt arc welding without a protecting screen fitted with the right kind of glass. Cheap glass is dear at any price, for the light rays thrown off from the arc are very dangerous to the eyesight. The guard should be so made as to not only protect the eyes from dangerous light rays, but should also protect the face and neck from flying sparks of metal.

A very good face mask made by Julius King Optical Co., New York, is shown in Fig. 18. These masks are made of fiber

and provision is made for a free circulation of air between the front and the face, not only keeping the operator cool, but preventing the tendency of the lenses to fog. The masks are supported by bands over the head and it is said that weight

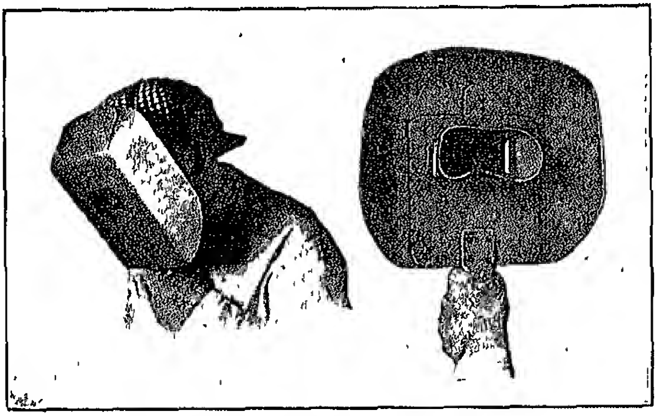


FIG. 19.—King Hand Shields.

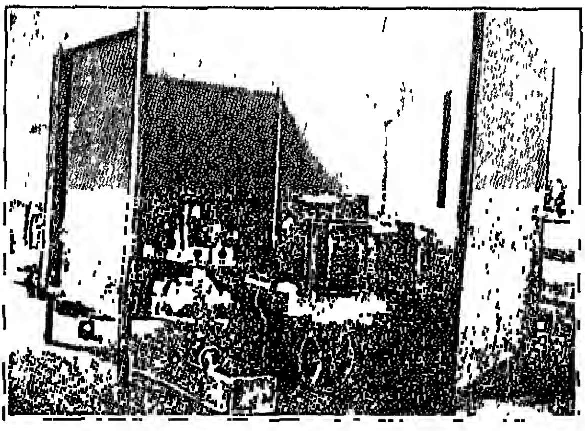


FIG. 20.—Method of Using Screens to Protect Others.

is not apparent and that they are as comfortable to wear as a cap. Two styles are made—with and without side screens. The one without screens may be had with combination lenses tinted for acetylene or electric welding or with any other tint for specific work. The one with side screens, providing side vision,

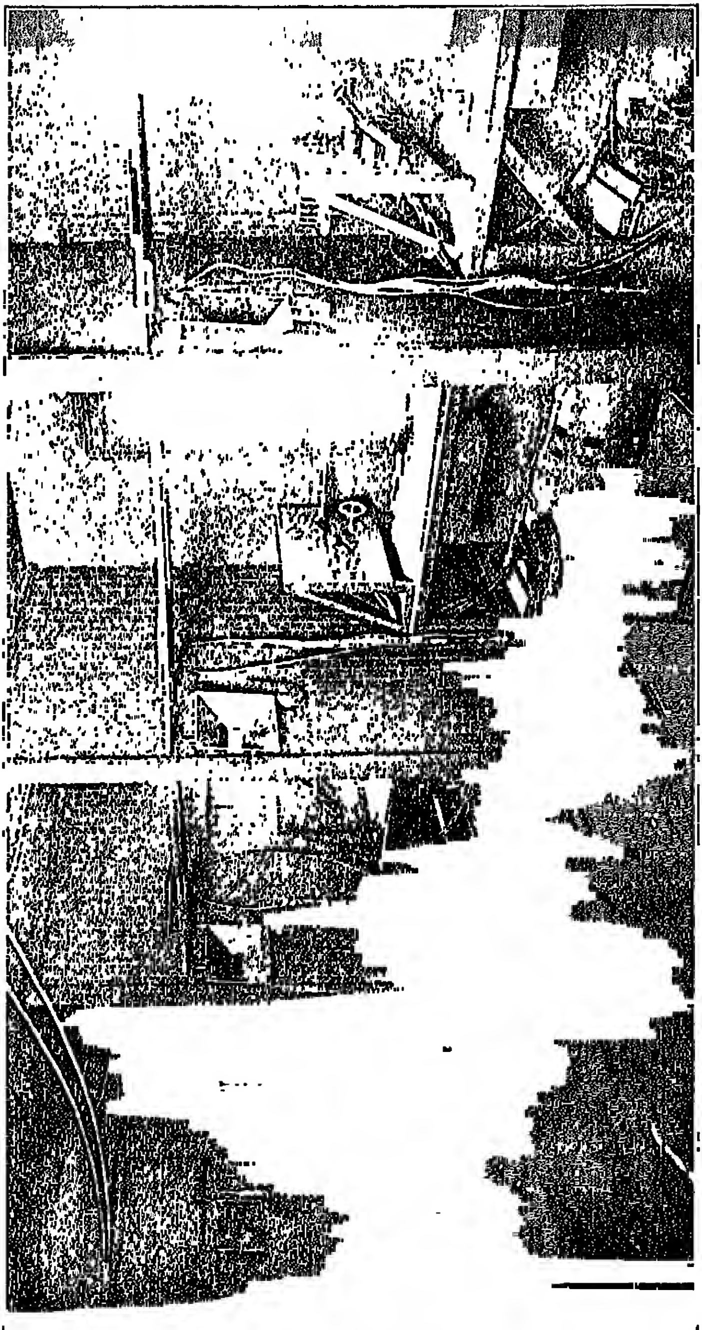


Fig. 21.—Individual Stalls for Instruction Work.

is fitted either with combination lenses or with clear Saniglass lenses. A hand shield is shown in Fig. 19.

In arc welding in the open, other workmen or onlookers are liable to injury as well as the welders, so screens should be placed around the work to conceal the light rays from the view of others besides the welder. Such an arrangement is shown in Fig. 20.

Where repetition work is to be done, it is well to provide individual stalls or booths, somewhat similar to the one shown in Fig 21. These were designed for use in the welding schools under the supervision of the Lincoln Electric Co. For actual shop work, curtains or screens should be provided back of the welders.

It must be remembered also, that owing to the presence of ultra-violet rays, severe flesh burns may result with some people if proper gloves and clothing are not worn—especially when using the carbon arc.

Selecting a Welding Outfit.—Welding outfits may be of the stationary or the portable type. These may also be divided into motor-generator sets and the "transformer" types. Both d.c. and a.c. current may be used primarily, depending on the apparatus employed and the source of current available.

Regarding the selection of any particular outfit J. M. Ham, writing in the *General Electric Review* for December, 1918, says:

Few things electrical have in so short a period of time created such wide-spread interest as that of arc welding. Engineers having to do with steel products, in whatever form produced or in whatever way employed, have investigated its uses not only as a building agent when applied to new material but as a reclaiming agent for worn or broken parts. In both cases its possibilities as a means of greatly increasing output and in saving otherwise useless parts at a small fraction of their original or replacement value has proved astounding.

Out of these investigations have grown several systems of arc welding.

To exploit these is the duty of the sales department and the measure of its success depends upon the quality of service rendered.

The difficulties of giving service are perhaps not fully appreciated. Where so many systems have been called for and

where so many individual ideas have to be met, the problems of the manufacturer become multiplied.

During a period of freight congestion when locomotives were in unprecendented demand, an engine was run into the repair shop with slid flat spots on each of the eight driving wheels, and orders were issued to return it ready for service in record time. In three hours repairs had been completed by means of the electric arc (to have put on new tires would have required three to four days) and the locomotive was out on the road. Many other achievements as remarkable as these have been obtained.

It would seem that having demonstrated the success of arc welding for a given line of work, others similarly engaged would be keen to take advantage of it; but that is true only in part, possibly because this is a "show me" age.

When it becomes apparent to the investigator of arc welding possibilities that the process fulfills his requirements, the question of what system to employ confronts him; salesmen are on the job to tell him about their particular specialties. He is informed that the real secret of welding is having the proper electrode (the salesman's special kind); it must be covered or bare, as the case may be, and contain certain unnamed ingredients. The merits of the direct-current system are extolled. Alternating-current outfits are advocated by others, it being claimed that they bite deeper and weld if the arc is held. The prospective buyer retires with a headache to think it over.

There is no mystery about arc welding. It is being done with all sorts of outfits and many varieties of electrodes. It can even be done from power lines with resistance in series with the arc. But these systems differ widely in essentials, just as in the case of automobiles. We can buy a cheap car or an expensive car, and in either event we get just about what we pay for.

The arc-welding set must pay its way. It must earn dividends and conserve materials, and when properly selected and applied does both of these things to a degree quite gratifying. To the discriminating purchaser it is not sufficient merely to know that an outfit will make a weld, he wants to know if it is the best weld that can be made, if it can be made in the shortest possible time, and whether the ratio between cost of the entire system

to the savings affected is the lowest obtainable. He doubtless will, if the work is of sufficient magnitude to warrant, establish a welding department with a trained arc welding man in charge, and see that this department stands on its own feet. By so doing he places responsibility on a man who knows what to do and how to do it—a friend rather than a foe of the system. He will, other things being anything like equal, respect the opinion of the operator in the selection of the system to be employed, because it is better to provide a man with tools he is familiar with and prefers to use, rather than to force him to use something with which he is unfamiliar or which he regards with disfavor.

Obviously, the purchaser wishes to know that the companies he is dealing with are reliable and responsible, that the experience back of the salesmen is sufficient to warrant faith in his product. It is important to know the amount of power required per operator and whether drawing the needed amount from his own lines or from those of the power company will interfere with the system, and if so to what extent, and what, if any, additional apparatus will be needed to correct the trouble. Having determined these things to his satisfaction, he can install his arc-welding system with a considerable degree of assurance that there will be a decided saving in time, men, and money, and a genuine conservation of materials.

EYE PROTECTION IN IRON WELDING OPERATIONS

In the *General Electric Review* for Dec., 1918, W. S. Andrews says in part:

Radiation from an intensely heated solid or vapor may be divided under the three headings:

(1) Invisible infra-red rays
(2) Visible light rays
(3) Invisible ultra-violet rays.

There is no clear line of demarcation between these divisions, as they melt gradually one into the other like the colors of the visible spectrum. When the heated matter is solid, such as the filament of an incandescent lamp, the visible spectrum is usually continuous, that is, without lines or bands; but when it is in the form of a gas or vapor, as in the iron arc used for welding operations, the spectrum is divided up into bands or is crossed by lines which are characteristic of the element heated.

The radiations under the foregoing three headings, although of common origin, produce very diverse effects upon our senses. Thus, the infra-red rays produce the sensation of heat when they fall on our unprotected skin, but they are invisible to our eyes. The visible light rays enable us to see; but we have no sense that perceives the ultra-violet rays, so that we know of them only by their effects.

The intense glare emitted in the process of arc welding consists of a combination of all these rays, and special safety devices are required to protect the operator from their harmful effects.

For welding with acetylene and for light electric welding, it may be necessary only to protect the eyes with goggles fitted with suitable colored glasses.

A hand shield made of light wood, and which has a safety colored glass window in the center is also sometimes used. This device is used for medium weight electric welding done with one hand. The shield serves the double purpose of protecting the eyes of the operator and also shielding his face from the heat rays and the ultra-violet radiation, which might otherwise cause a severe sunburn effect.

For heavy electric welding, which requires the use of both hands, it is common practice for the operator to protect his eyes and neck with a helmet fitted with a round or rectangular window of safety glass. These helmets are usually made of some strong light material such as vulcanized fiber and are designed so that they can be slipped on and off easily, the weight resting on the shoulders of the operator.

There are a great many different kinds of special safety glasses on the market, and many combinations of ordinary colored glass are also in common use, so a brief discussion of this very important subject is in order.

It is well known that the normal human eye shows considerable chromatic aberration towards the red and blue-violet ends of the spectrum and that this defect is completely corrected in regard to the middle colors. It, therefore, naturally follows that a much clearer definition of an object is obtained by combinations of yellow-green light than by red alone, or especially by blue or violet light alone. The eye is also more sensitive to the yellow and green rays than it is to the red and blue rays; or in other words, yellow-green light has the highest luminous efficiency. This may easily be verified by looking at a sunlit landscape or fleecy clouds in a blue sky through plates of different colored glass. A glass of a light amber color or amber slightly tinted with green will clearly bring out details that are hardly observable without the glass, and which will be obscured entirely by a blue or violet glass. It is therefore obvious that in order to obtain *the clearest definition or visibility with the least amount of glare,* the selection of the *color tint* in safety glasses should properly be decided by an expert; but the *depth of tint or,* in other words, the *amount of obscuration* may be determined best by the operator himself, owing to the individual difference in visual acuity which will permit one man to see clearly through a glass that would be too dark for another man.

When the invisible infra-red rays encounter any material which they

cannot penetrate, or which is opaque to them, they are absorbed and are changed into heat. Hence, they are frequently termed heat rays. It is, therefore, very necessary to guard the eyes from these rays; and although they are absorbed to a certain extent by ordinary colored glass, this is not sufficient protection against any intense source. There are, however, several kinds of glass, which, although fairly transparent to visible light, are wonderfully efficient in absorbing heat. The effects of even low-power heat rays, when generated in close proximity to the eyes for considerable time, are often serious, as is evidenced by the fact that glass blowers, who use their unprotected eyes near to hot gas flames of weak luminous intensity, are frequently afflicted with cataract which might be positively avoided by wearing properly fitted spectacles.

In selecting colored glasses, great care should be taken to discard all samples that show streaks or spots, as these defects are liable to produce eye-strain. The glass should be uniform in color and thickness throughout, and the colored plate should be protected from outside injury by a thin piece of clear glass that can easily be renewed.

Table II indicates roughly the percentage of heat rays transmitted by various colored glasses of given thickness. The source of heat used was a 200-watt, gas-filled Mazda lamp operating at a temperature of about 2400 deg. C. Although the figures are substantially correct for the samples tested, they would necessarily vary somewhat for other samples of different thickness and degrees of coloration, so that they can be taken only as a general guide for comparative purposes. Examination of the table will show that the last three, or commercial samples, all show better than 90 per cent exclusion of the heat rays.

TABLE II.—QUALITIES OF VARIOUS KINDS OF GLASS

Kind of Glass	Thickness in Inches	Per Cent Heat Rays Transmitted
Clear white mica	0.004	81
Clear window glass	0.102	74
Flashed ruby	0.097	69
Belgium pot yellow	0.120	50
Cobalt blue	0.093	43
Emerald green	0.100	36
Dark mica	0.007	15
Special light green glass	0.095	10
Special dark glass	0.096	4
Special gold-plated glass	0.114	0.8

As to the invisible ultra-violet rays, they are principally to be feared not only because they are invisible, but because we have no organ or sense for detecting them, and we can only trace their existence by their effects. In all cases, however, when we are forewarned of their presence, they are very easily shielded, for there are only a few substances which

are transparent both to visible light and to ultra-violet radiation. Foremost among these latter substances, because it is most common, is clear natural quartz or rock crystal, from which the so-called "pebble" spectacle lenses are made. Fluorite and selenite are also transparent to ultra-violet rays, but these crystalline materials are rare and not in common use. However, a moderate thickness of ordinary clear glass, sheets of clear or amber mica, and of clear or colored celluloid or gelatine are opaque to these dangerous rays. As a case in point, it is well known that the mercury vapor lamp, when made with a quartz tube, is an exceedingly dangerous light to the eye, being a prolific source of ultra-violet radiation, so that when it is used for illumination, it is always carefully enclosed in an outer globe of glass. When the mercury vapor lamp, however, is made with a clear glass tube it is a harmless, if not very agreeable, source of light, because the outer tube of clear glass is opaque to the ultra-violet rays that are generated abundantly within it by the highly luminescent mercury vapor.

When operating with a source of light that is known to be rich in ultra-violet rays, such as the iron arc in welding operations, it is not sufficient to guard the eyes with ordinary spectacles because these invisible rays are capable of reflection, just the same as visible light, and injury may easily ensue from slanting reflections reaching the eye behind the spectacle lenses. Goggles that fit closely around the eyes are the only sure protection in such cases. Also, when using a hand shield it should be held close against the face and not several inches away from it.

It may here be mentioned that the invisible ultra-violet rays, when they are not masked or overpowered by intense visible light, produce the curious visible effect termed "fluorescence" in many natural and artificial compounds. That is, these rays cause certain compounds to shine with various bright characteristic colors, when by visible light alone they may appear pure white or of some weak neutral tint. Thus, natural willemite, or zinc silicate, from certain localities (which may also be made artificially) shows a bright green color under the light from a disruptive spark between iron terminals; whereas this compound is white or nearly so by visible light. Also, all compounds of salicylic acid, such as the sodium salicylate tablets which may be bought at any drug store, are pure white when seen by visible light, but show a beautiful blue fluorescence under ultra-violet rays. Many other chemical compounds could be mentioned which possess this curious property, but the above substances will suffice to illustrate the effect of fluorescence produced by ultra-violet rays, and by which these rays may be thereby detected. It must, however, be noted that these substances will only show their fluorescent colors very faintly when viewed by the light of the low-tension iron arc used in welding, because the intense visible light of this arc will overpower the weaker effect of the invisible ultra-violet rays. The true beauty of fluorescent colors can only be seen under a high-tension disruptive discharge between iron terminals, the visible light in this case being weak while the ultra-violet rays are comparatively intense.

Summarizing the effective means for eye protection against the various

harmful radiations that are particularly associated with welding operations:

(1) The intense glare and flickering of the visible rays should be softened and toned down by suitably colored glasses, selected by an expert and having a depth of coloration which shows *the clearest definition combined with sufficient obscuration of glare,* which last feature can be best determined by the individual operator.

(2) When infra-red rays are present to a dangerous degree, a tested heat-absorbing or heat-reflecting glass should be employed, either in combination with a suitable dark colored glass, when glaring visible light is present, or by itself in cases where the visible rays are not injuriously intense.

(3) In guarding the eye from the dangerous ultra-violet rays, it must be carefully noted that "pebble" lenses are made from clear quartz or natural rock crystal, and this material being transparent to these rays offers *no protection* against their harmful features. On the other hand, ordinary clear glass is a protection against these rays when they are not very intense, but dark-amber or dark-amber-green glasses are absolutely protective. Glasses showing blue or violet tints should be avoided, excepting in certain combinations wherein they may be used to obscure other colors.

CHAPTER III

DIFFERENT MAKES OF ARC WELDING SETS

In showing examples of different makes and types of arc welding sets, only enough will be selected to cover the field in a general way, and no attempt whatever will be made to make the list complete.

The General Electric Co., Schenectady, N. Y., puts out the

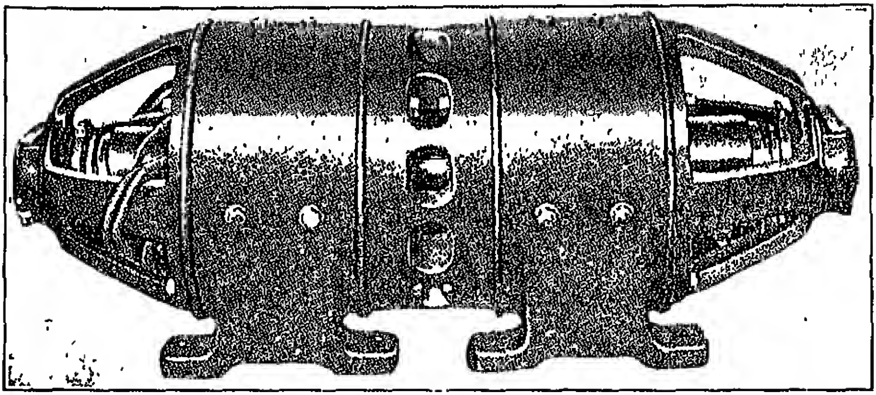


FIG. 22.—General Electric 3-KW., 1700-R.P.M., 125-60-20-V. Compound-wound Balancer-Type Arc Welding Set.

constant energy metallic electrode set shown in Fig. 22. This, however, is but one type of its machines as this company makes a varied line covering all needs for welding work. Two of their commonly used, up-to-date sets are illustrated in Figs. 131 and 132, Chapter VIII.

This particular machine combines high arc efficiency and light weight. The balancer set is of the well-known G-E standard "MCC" construction. It is built for operation on 125-v., d.c. supply circuits, which may be grounded on the positive side only, and is rated "MCC" 3 kw., 1,700 revolution, 125/60/20 v., com-

pound-wound, 150 amperes, RC-27-A frames, the two armatures being mounted on one shaft and connected in series across the 125-v. supply circuit, one welding circuit terminal being taken from the connection between the two armatures and the other from the positive line. By this means each machine supplies part of the welding current and, consequently, its size and weight is minimized. The design of the fields and their connections is such that the set delivers the voltage required directly to the arc without the use of resistors or other energy-consuming devices. The bearings are waste packed: this type of bearing

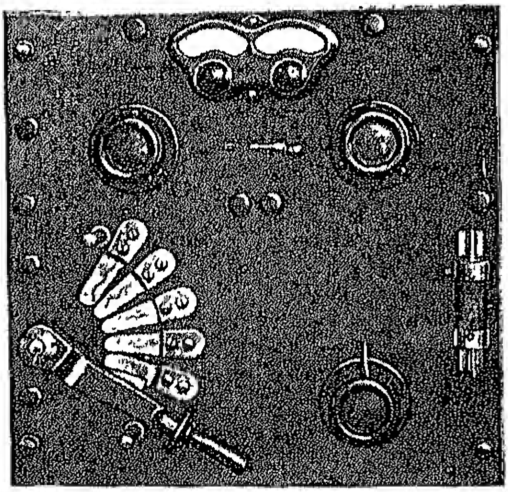


FIG. 23.—Welding Control Panel for Balancer Set.

being desirable in a set which is to be made portable either for handling by a crane or for mounting on a truck.

The welding control panel for the balancer set is shown in Fig. 23. This panel consists of a slate base, 24-in. square, which is mounted on 24-in. pipe supports for portable work and on 64-in. pipe supports for stationary work.

The entire set consists of one ammeter, one voltmeter, one dial switch, two field rheostats (motor and generator) one starting equipment with fuse, one reactor mounted on the pipe frame work of panel. The ammeter and voltmeter are enclosed in a common case. The ammeter indicates current in the welding

circuit and the voltmeter is so connected that by means of a double-throw switch, either the supply line voltage or the welding line voltage can be read.

The dial switch is connected to taps in the series field of

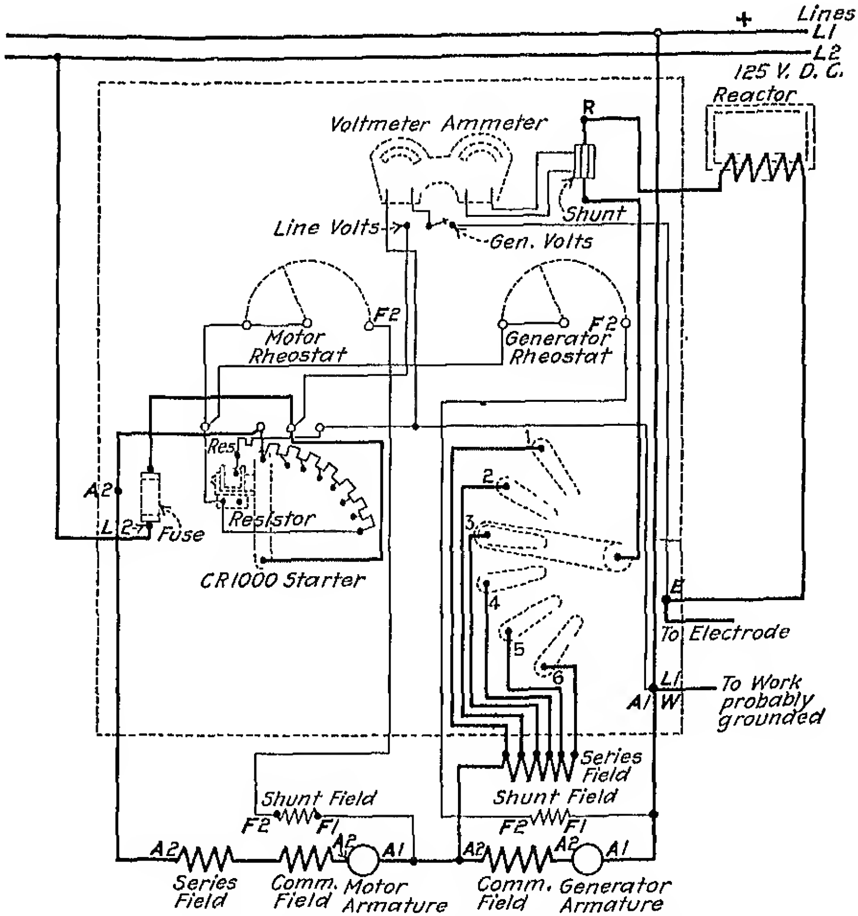


FIG. 24.—Balancer and Control Panel Connections for General Electric Constant-Energy Constant-Arc Set.

the generator, the field being connected to oppose the main field. This feature provides the current control by which six steps are obtained of the approximate values of 50, 70, 90, 110, 130 and 150 amp., which enables the operator to cover a very wide range.

In addition, if intermediate current values are required, they can be obtained by means of the generator field rheostat.

A small reactor is used to steady the arc and current both on starting and during the period of welding.

Arc welding is usually done on metal which is grounded and this is especially unavoidable in ship work, where the ship structure is always well grounded. Since successful operation requires that the positive terminal be connected to the work the supply circuit should be safely grounded on the positive side.

Where a 125-v., d.c. supply system is not available, standard

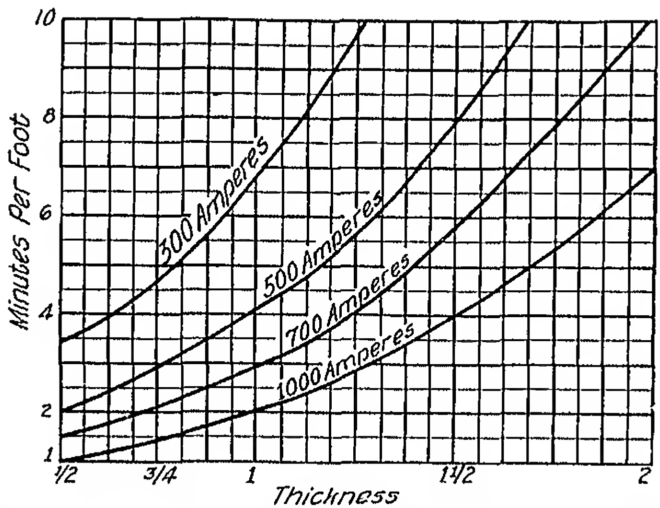


FIG. 25.—Carbon Electrode Cutting Speeds for Different Thicknesses of Plate.

"MIC" or "MCC" sets are furnished to supply power at 125 v., the motor being either 3-phase, 60-cycle, 220, 440 or 550 v., or d.c., 230 or 550 v., and in three capacities, $5\frac{1}{2}$ kw., 7 kw., and 15 kw. With each motor generator set there is supplied a panel containing generator field rheostat and motor starter, which may be mounted beside the balancer panel. A diagram showing the balancer and control panel is shown in Fig. 24.

The constant energy arc-welding equipment supplies, to the arc, practically constant energy throughout the welding range for metallic electrode welding only. If the arc is lengthened slightly the voltage increases and the current decreases, the total

TABLE III.—DATA FOR METALLIC ELECTRODE BUTT AND LAP WELDS

BUTT WELDS BY METALLIC ELECTRODE—LAP WELDS WILL BE APPROXIMATELY THE SAME AS TWO BUTT WELDS—POWER 3C. PER KW.-HR.:—LABOR 30C. PER HR.—ELECTRODE 5C. PER LB.

Thickness of Metal	Diameter Electrode	Speed Ft. per Hr.	Amperes	Mean Kw. at 60 Volts	Mean Kw. at 70 Per Cent Eff.	Approx. Electrode per Hr. Lb.	Power per Hour c.	Labor c.	Electrode c.	Total per Hr. c.	Total per Ft. c.
1/16	1/16	20	High 50 Mean 40 Low 30	1.8	2.0	0.9	6.0	30	4.5	40.5	2.0
1/8	1/8	16	90 70 50	1.4	3.6	1.4	10.8	30	7.0	47.8	3.0
1/4	1/8 or 3/16	10	125 100 70	2.0	5.1	3.1	15.3	30	15.5	60.8	6.1
3/8	3/16 or 1/4	6.5	150 125 100	2.5	6.4	3.6	19.2	30	18	67.2	10.3
1/2	1/4	4.3	150 140 120	2.8	7.2	3.8	21.6	30	19	70.5	16.4
5/8	1/4	2.8	150 125	3.0	7.7	3.4	23.1	30	17	70.1	25.4

NOTE.—The figures given for power, labor and material are arbitrary and may be changed to suit local conditions.

energy being practically constant. As the voltage required by the arc varies, the generator readjusts itself to this condition and automatically supplies the required voltage; the remainder being utilized by the motor end of the set. The interchange of voltage between the motor and generator is practically instantaneous, no perceptible lag occurs. This feature is valuable when metal drops from the electrode and causes an instantaneous increase in current. The commutation is sparkless and the weld-

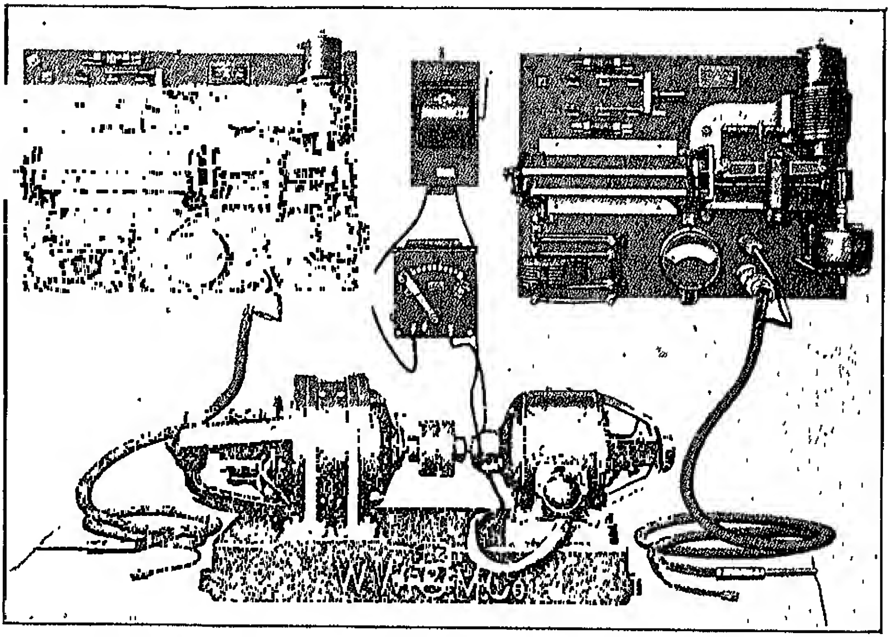


FIG. 26.—Wilson Two-Arc, 300 Amp., "Plastic Arc" Welding Set.

ing circuit may be short-circuited without injury to the machine.

In connection with welding with an outfit of this kind, the practical man and student will find Table III of considerable interest. For sheet steel cutting using the carbon arc, the chart Fig. 25 is given.

The Wilson Outfit.—The Wilson "plastic arc" process and apparatus was first developed in railroad work by the Wilson Welder and Metals Co., New York, in order to enable the welder to control the heat used. By this system it is claimed

that any number of operators can work from one large machine without one welder interfering in any way with the work of another. Each operator can have properly controlled heat and a steady arc at the point of application. This system was

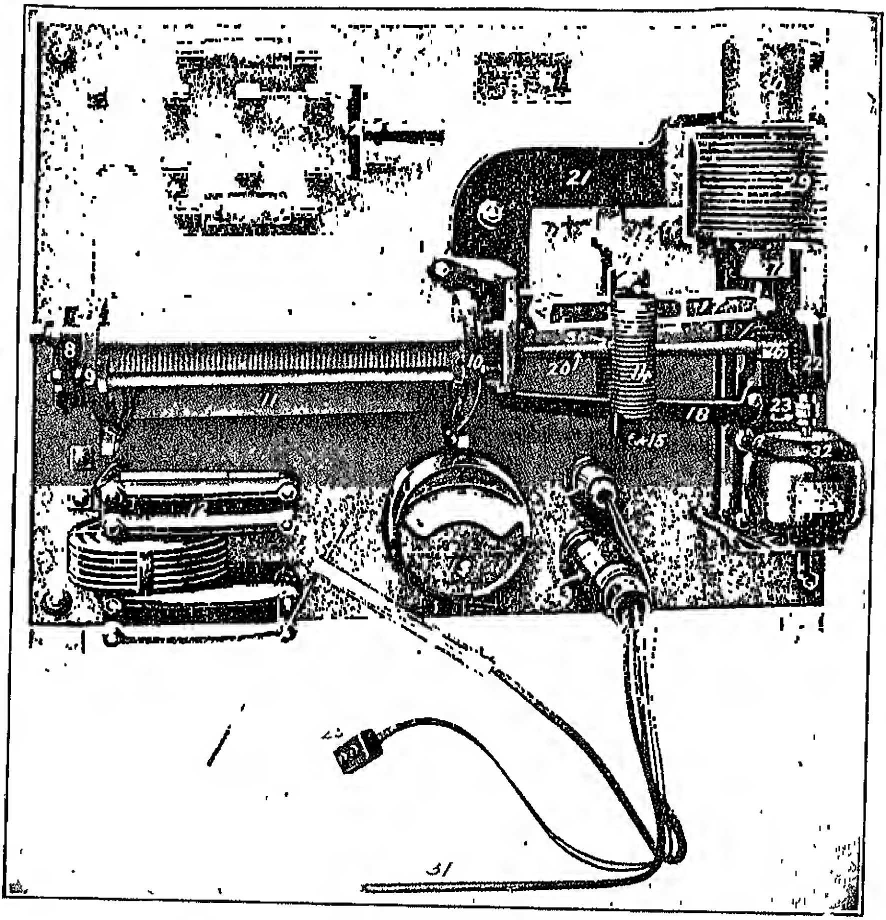


FIG. 27.—Welding and Cutting Panel for Wilson Set.

largely used in the repair of the damaged engines on the German ships which were seized by us. By regulating the heat it is claimed that any metal can be welded without preheating.

A two-arc set is shown in Fig. 26 and a close-up of a control panel in Fig. 27.

This outfit consists essentially of a constant voltage generator driven by any constant-speed motor, all mounted on a common bedplate. The regulation of the welding current is maintained by means of a series carbon pile acting as a series resistance of varying quantity under the action of increasing or decreasing mechanical pressure. This pressure is produced by means of a series solenoid operating mechanically on a lever and spring system which varies the pressure on the carbon pile inversely as the current in the main circuit. This establishes a constant current balance at any predetermined adjustment between a maximum and minimum range designed for. The change in adjustment is controlled by the operator at the point of work by means of a small pilot motor which shifts the lever center of the pressure mechanism, thereby raising or lowering the operating current. This system maintains a constant predetermined current at the arc regardless of the arc length. The operation of the mechanism is positive and quick acting. A special series choke-coil is mounted on the control panel for use as a cutting resistance.

"Plastic Arc" Dynamotor Unit.—The "plastic arc" welding unit illustrated in Fig. 28, while embodying the same fundamental principles as the foregoing, is a later model. This set is composed of a dynamotor and current control panel. The generator is flat-compound wound, and maintains the normal voltage of 35 on either no load or full load.

The control panel has been designed to provide a constant-current controlling panel, small in size, of light weight, simple in operation and high in efficiency. The panel is of slate, 20 in.×27 in., and on it are mounted a small carbon pile, a compression spring, and a solenoid working in opposition to the spring. The solenoid is in series with the arc so that any variation in current will cause the solenoid to vary the pressure on the carbon pile, thereby keeping the current constant at the value it is adjusted for.

Three switches on the panel provide an easy means of current adjustment between 25 and 175 amperes. The arrangement of the welding circuit is such that 25 amperes always flow through the solenoid when the main switch is closed, whether the welding current is at the minimum of 25 amperes or the maximum of 175 amperes. The balance of the welding

current is taken care of in by-pass resistances shunted around the solenoid.

This outfit can be furnished as a dynamotor unit, with standard motor characteristics as follows: 110 volts or 220 volts direct current, or 220 or 440 volts, 60 cycle, 2 or 3 phase, alternating current; also as a gasoline-driven unit, or it can

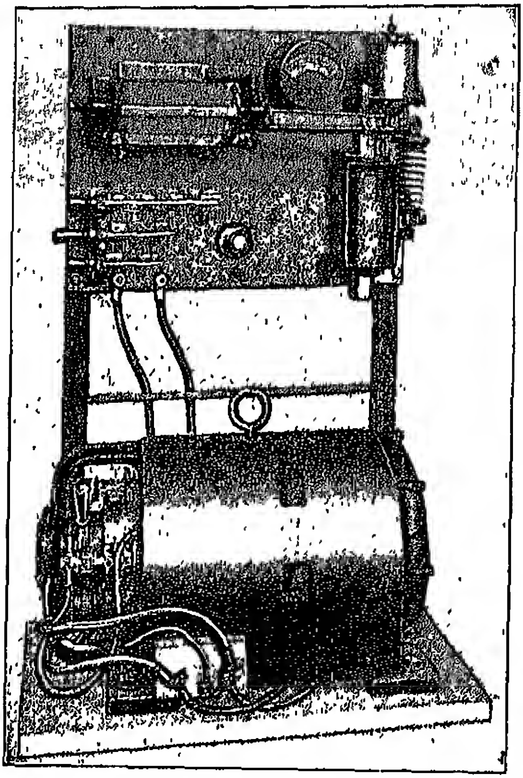


FIG. 28.—"Plastic-Arc" Dynamotor Welding Unit.

be furnished without a motor, to be belt driven. The normal generator speed is 1800 r.p.m. The net weight is 800 lb. with direct-current motor, 807 lb. with alternating-current motor, 1200 lb. with gasoline engine, and 550 lb. as a belted outfit without motor. The sets can be mounted on a truck for easy portability if desired.

The Lincoln Outfit.—The portable arc-welding outfit illus-

trated in Fig. 29 is the product of the Lincoln Electric Co., Cleveland, Ohio. The outfit is intended for operation where electric current is not available and consists of a 150-amp. arc-welding generator direct connected to a Winton gasoline engine. An interesting feature of the machine is the method used to insure a steady arc and a constant and controllable heat. A compound-wound generator is used, the series wind-

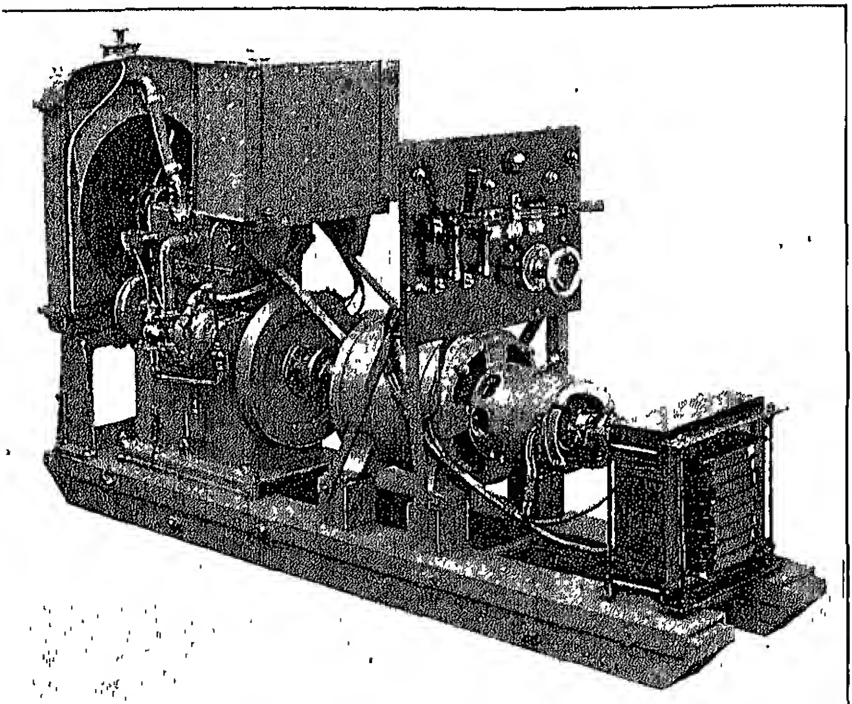


FIG. 29.—Lincoln Self-Contained Portable Set.

ings of which are connected to oppose the shunt field, the two windings being so proportioned that the voltage increases in the same ratio that the current increases, thus limiting the short-circuit current. Another important effect of this is that the horsepower, and therefore the heat developed for a given setting of the regulator switch shown on the control board above the generator remains practically constant. It is claimed that this method of control gives considerably more work

on a given amount of electricity than where the machines use the ballast resistance. Additional arc stability is insured by the stabilizer at the right of the illustration, this being a highly inductive low-resistance coil connected in the welding circuit and serving to correct momentary fluctuations of current.

Westinghouse Single-Operator Electric Welding Outfit.—The single-operator electric arc-welding equipment shown in Fig. 30 is manufactured by the Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa. The generator

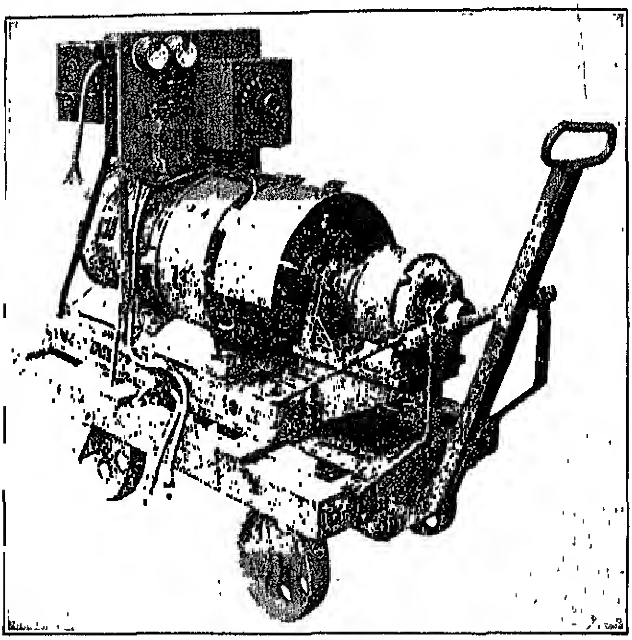


Fig. 30.—Westinghouse Single-Operator Portable Outfit.

operates at arc voltage and no resistance is used in circuit with the arc. The generator is designed to inherently stabilize the arc, thereby avoiding the use of relays, solenoid control-resistors, etc.

The generator has a rated capacity of 175 amp. and is provided with commutating poles and a long commutator, which enable it to carry the momentary overload at the instant of striking an arc without special overload device. Close adjustment of current may be easily and quickly made, and, once

made, the amount of current at the weld will remain fixed within close limits until changed by the operator. There are twenty-one steps provided which give a current regulation of less than 9 amp. per step and make it much easier for a welder to do vertical or overhead work.

The generator is mounted on a common shaft and bedplate with the motor. A pedestal bearing is supplied on the commutator end and carries a bracket for supporting the exciter which is coupled to the common shaft. Either d.c. or a.c. motors can be supplied. Where an a.c. motor is used leads

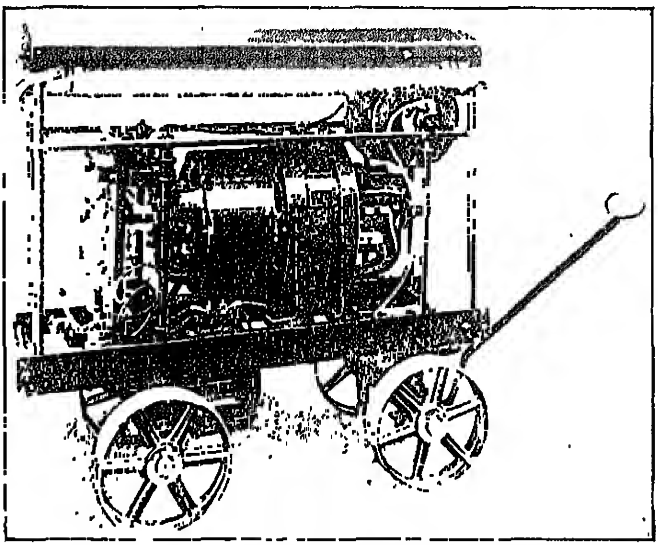


FIG. 31.—U. S. L. Portable, A-C. Motor-Generator Set.

are brought outside the motor frame for connecting either 220- or 440-v. circuits. An electrician can change these connections in a few minutes' time. This feature is desirable on portable outfits which may be moved from one shop to another having a supply circuit of different voltages. For portable service, the motor-generator set with the control panel is mounted on a fabricated steel truck, equipped with roller-bearing wheels. The generator is compound-wound, flat compounded, that is, it delivers 60 v. at no-load and also at full-load.

The U. S. Light and Heat Co.'s Outfit.—The portable outfit, Fig. 31, is made by the U. S. Light and Heat Corp., Niagara Falls, N. Y. It is 28 in. wide, 55 in. high, 54 in. long, and will pass through the narrow aisle of a crowded machine shop. It weighs 1,530 lb. complete. In case a d.c. converter is used, the weight is about 125 lb. less. Curtains are provided to keep out dirt. A substantial cable reel is provided carrying two 50-ft. lengths of flexible cable for carrying the current to the arc. The reel is controlled by a spring which prevents the paying out of more cable than the welder needs. The outfit is made in several models to use 4 kw., 110-220-440-550 v., 2 and 3 phase, 25 and 60 cycle.

The Arc Welding Machine Co.'s Constant-Current Closed-Circuit System.—The constant-current closed-circuit arc welding

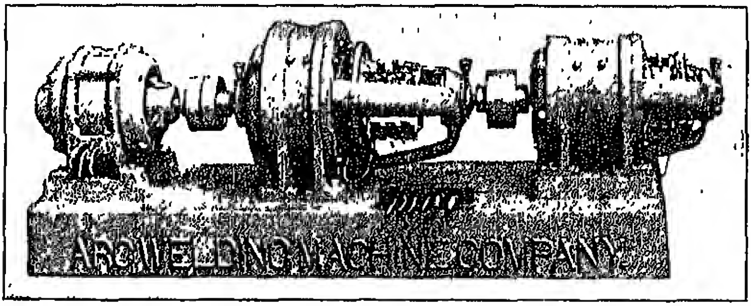


Fig. 31A.—The Arc Welding Machine Co.'s Outfit.

system developed by the Arc Welding Machine Co., New York, permits the use of an inherently regulating generator with more than one arc on a single circuit. This system is claimed to be especially adapted to production welding applications.

The method has all the advantages of series distribution, namely, the size of wire is uniform throughout the system and carries a uniform current, independent of the length of the circuit as well as of the number of operators. The circuit is simply a single wire of sufficient cross-section to carry the current for one arc, run from the generator to the nearest arc, from there to the next, and so on back to the generator. Wherever it is desired to do welding, a switch is inserted in the line, and a special arc controller provided with suitable connections is plugged in across the switch whenever work

is to be done. These controllers may be made portable or permanently mounted at the welding station.

The set shown in Fig. 31A consists of two units: The generator proper which furnishes the energy for welding, and the regulator which automatically maintains the current at a constant value. The regulator is excited from a separate source, and, by varying its excitation with an ordinary field rheostat, the main welding current may be set at any value within the range of the machine that is desired, and once set it will automatically maintain that value.

Each arc that is operated on the system is equipped with an automatic controller which serves two essential purposes:

1—It maintains at all times the continuity of the circuit, so that one arc cannot interfere with any of the others when it comes on, or goes out of, the circuit.

2—It controls automatically the heat which can be put into the metal of the weld.

The current through the arc, together with the size of the electrode, determines the flow of metal from the electrode, and this current is adjusted by shunting a portion of the main current around the arc. The regulation characteristic of the arc may be adjusted by a series parallel resistance, which is one of the special features. When doing work on very thin, light metals, especially where the weld must be tight, it is necessary that fusion take place from the first instant the arc is struck. If the heat of the arc is exactly right for continuous operation, it will not be enough at the first instant, and if it is sufficient to produce fusion at once, then it will be too much a few seconds later. On this account a special type of controller is used for such work which provides for automatic reduction at a definite time after the arc is actually started, and continuing for a definite time and at a definite rate. Both periods of time and the rate and magnitude of the current change are adjustable.

For a given flow of metal through the arc the temperature of the metal is determined by the length of the arc, that is, by the voltage. With this controller, the length of the arc limited by the voltage is adjusted to suit the work and the operator, and if exceeded, the arc is short-circuited automat-

ically and remains short-circuited until the welder is ready to begin again.

Provision is also made for stopping the arc at will without lengthening it. Therefore it is claimed that with this system it is impossible to draw a long arc and burn the metal. The arc is not broken when the welding operation is stopped, but is killed by a short-circuit which is placed across it.

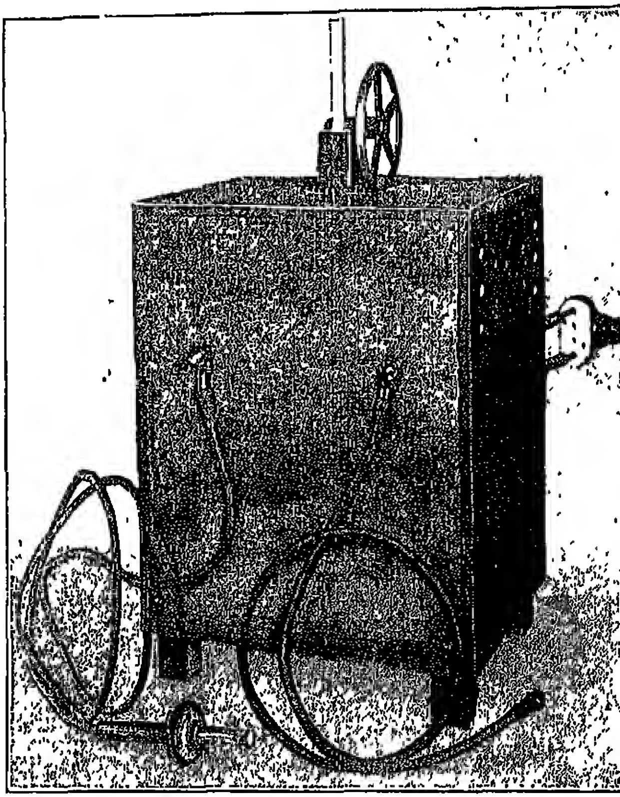


Fig. 32.—Zeus Arc-Welding Outfit.

Stopping an arc by short-circuiting and limiting the heat production in the same way is a patented feature.

"Zeus" Arc-Welding Outfit.—The "Zeus" arc-welding outfit shown in Fig. 32 is a product of the Gibb Instrument Co., 1644 Woodward Ave., Detroit, Mich. In this device the motor-generator customarily used has been supplanted by a trans-

former with no moving parts. The outfit is built on a unit system, which allows the installation of a small outfit, and if the work becomes heavier a duplicate set may be connected in parallel. One of the features of the machine is the arrangement for regulation. It is not necessary to change any connection for this purpose, as a wheel connected with a secondary and placed on the top of the case raises and lowers this secondary, and provides the regulation of current necessary for

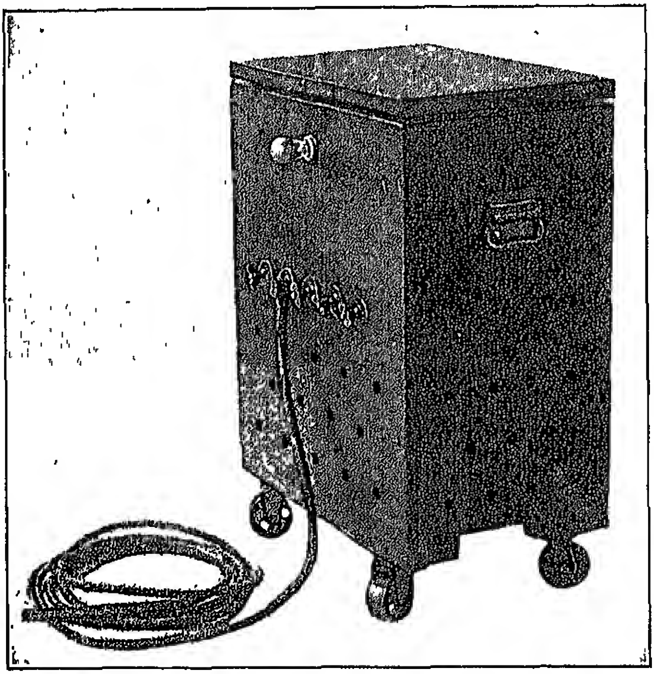


FIG. 33.—Arcwell Outfit for Alternating Current.

different sizes of electrodes. The inherent reactance of the outfit automatically stabilizes the arc for different arc lengths.

The Arcwell Outfit.—The Arcwell Corporation, New York, has on the market an electric welding apparatus built for operation on alternating current of any specified voltage or frequency. It is shown in Fig. 33. It differs from the company's standard outfit in that it is being put out expressly for the use of smaller machine shops and garages, its capacity not being sufficient to take care of heavy work on a basis of

speed. It will do any work that can be done by the larger machines, but the work cannot be performed as rapidly, the machine being intended especially for use by concerns who have only occasional welding jobs to perform. The machine weighs approximately 200 lb. and, being mounted on casters, it can be moved from one job to another.

Alternating-Current Arc-Welding Apparatus.—The Electric Arc Cutting and Welding Co., Newark, N. J., is now marketing the alternating-current arc-welding outfit shown in Fig. 34.

This illustration shows the entire apparatus for use on a

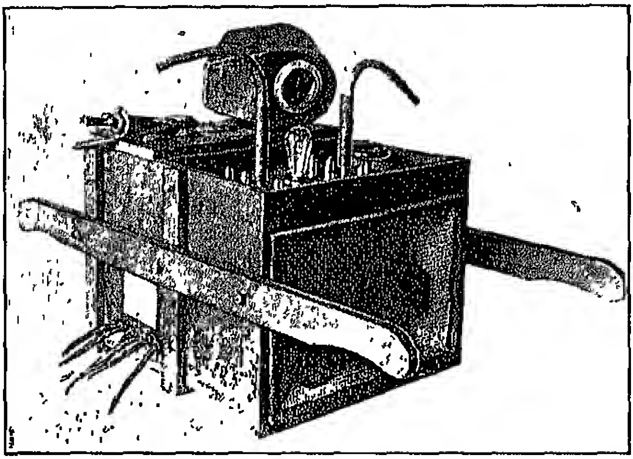


Fig. 34.—Apparatus Made by the Electric Arc Cutting and Welding Co.

single-phase circuit, the current being brought in through the wires seen protruding at the lower left corner.

The device consists principally of a transformer with no moving parts and is claimed to last indefinitely. In this apparatus, instead of holding either current or voltage constant as with direct-current sets, the wattage, or the product of voltage and current, is held constant. The alternating-current set holds the arc wattage without moving parts; hence the heat is substantially constant for any given setting, and it is claimed that as soon as any person becomes accustomed to the sound and sight of the arc and can deposit the molten metal where he desires it is impossible to burn the metal from too much heat or make cold-shut welds from too little heat. The amount

of heat generated is controlled by means of an adjusting handle on the transformer together with taps arranged on a plugging board. It is stated that the kilowatt-hours required to deposit a pound of mild steel with this machine varies from 1½ to 2¼.

Their largest set is a 60-cycle type weighing about 200 lb., which places it in the portable class. The set can be furnished for any a.c. power supply, but it is not advisable to use a greater voltage than 650 on the primary. The set can also be made single phase, two phase three wire, two phase four wire,

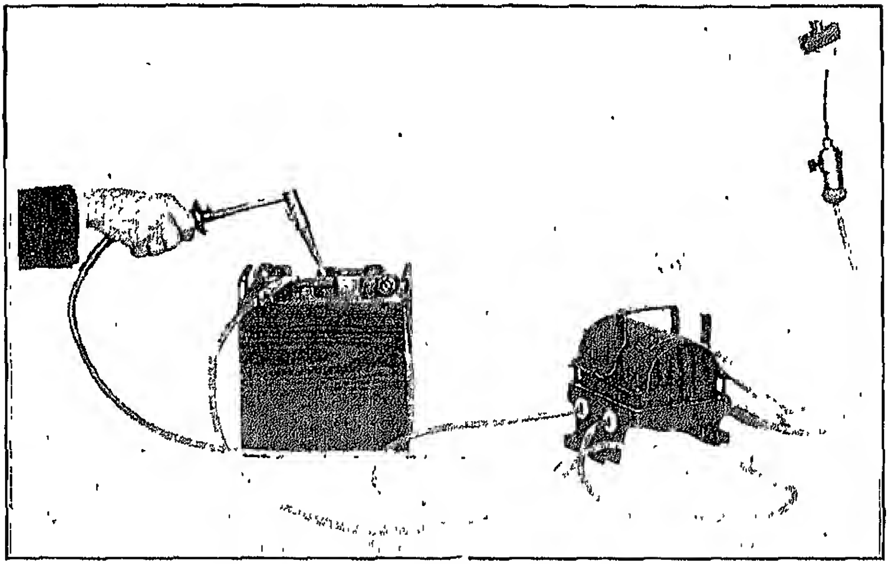


FIG. 35.—General Electric Lead-Burning Outfit.

to operate across the outside wires of the two-phase system or from a three-phase power supply. Polyphase sets are about 30 per cent heavier than the single-phase sets. In the two-phase machine balanced current can be drawn from each of the two phases by placing the sets across the outside wires. This is advocated, as it provides for leading current on one phase which brings up the total power factor of the system and a better power rate can be obtained. In polyphase circuits where more than one set is used single-phase sets can be distributed among the several phases.

The outfit can be made especially for welding and for cut-

ting or for combination welding and cutting and can make use of bare wire, slag-covered, gaseous fluxed or carbon electrodes. An operator's mask and the electrode holder used may be seen on top of the apparatus.

General Electric Lead-Burning Transformer.—This lead-burning transformer, Fig. 35, a product of the General Electric Co., Schenectady, N. Y., can be used for lead burning, soldering electric terminals, splicing wires and tinsmith jobs, and even brazing can be done by placing the work between a blunt carbon point and a piece of cast iron. The transformer is designed to be connected to the ordinary 110-v., a.c. lighting circuit. Heavy rubber-covered terminal leads are used to convey the low-voltage, heat-producing current to the work, one terminal ending in a clip for fastening to some convenient portion of the work while the other terminal has a carbon holder arranged with an insulated handle. When the welding carbon is brought into contact with the work the pointed end becomes intensely hot and melts the metal over a restricted area. It should be noted that no arc is drawn, the end of the carbon point being heated to such a temperature that the metal in the vicinity is melted. The device uses about 800 watts while in actual use, the consumption dropping to 4½ watts when the point is removed from the work. It is stated that the device is very convenient in plumbing, roofing and tank-building jobs, as well as other such work.

CHAPTER IV

TRAINING ARC WELDERS

Writing on the training of arc welders, in the *American Machinist*, April 15, 1920, O. H. Eschholz, research engineer of the Westinghouse Electric and Mfg. Co., Pittsburgh, says:

Many industrial engineers are now facing the problem of developing competent welders. This situation is attributed to the rapid growth of the metallic electrode arc-welding field as the result of the successful application of the process to war emergencies. The operator's ability, it is now generally conceded, is the most important factor in the production of satisfactory welds. To facilitate the acquirement of the necessary skill and knowledge, the following training course considers in their proper sequence the fundamental characteristics and operations of the bare metallic electrode arc-welding process.

It is well known that the iron arc emits a large quantity of ultra-violet radiation. Protection from the direct rays is usually afforded by the use of hand shields. Many uncomfortable burns, however, have been traced to reflected radiation. To secure adequate protection from both direct and reflected light it is necessary for the welder to use a fiber hood equipped with suitable glasses. Paper No. 325 of the Bureau of Standards on "Spectroradiometric Investigation of the Transmission of Various Substances" concludes that the use of amber and blue glasses will absorb most of the ultra-violet as well as infra-red radiation. To protect the operator from incandescent particles expelled by the arc, closely woven clothing, a leather apron, gauntlets and bellows-tongued shoes should be worn.

If the welding booth is occupied by more than one welder, it will be found desirable to equip each operator with amber or green-colored goggles to reduce the intensity of accidental

"flashes" from adjacent arcs after the welder has removed his hood.

The Welding Booth.—The difficulty of maintaining an arc is greatly increased by the presence of strong air currents. To avoid the resulting arc instability, it is desirable to inclose the welder on at least three sides, with, however, sufficient ventilation provided so that the booth will remain clear from fumes. By painting the walls a dull or matte black the amount of arc radiant energy reflected is reduced.

The electrode supply and means of current control should be accessible to the operator. When using bare electrodes the positive lead should be firmly connected to a heavy steel or cast-iron plate, mounted about 20 in. above the floor. This plate serves as the welding table.

Welding Systems.—Many commercial sets compel the operator to hold a short arc. This characteristic favors the production of good welds but increases the difficulty of maintaining the arc. By increasing the stability of the arc through the use either of covered electrodes, series inductances or increased circuit voltage and series resistance, the acquisition of the purely manipulative skill may be accelerated.

The Electrode Holder.—The electrode holder should remain cool in service, shield the welding hand from the arc, facilitate the attachment and release of electrodes, while its weight, balance and the drag of the attached cable should not produce undue fatigue. A supply of different types of covered and bare electrodes should be carried by the welding school so that the operator may become familiar with their operating and fusing characteristics.

The degree of supervision the welder is to receive determines the source of operator material. If the welding operations are to be supervised thoroughly and the function of the welder is simply that of uniting suitably prepared surfaces, the candidate may be selected from the type of men who usually become proficient in skilled occupations. If, however, the responsibility of the entire welding procedure rests upon the operator, he should be drawn from members of such metal trades as machinist, boilermaker, blacksmith, oxy-acetylene welder, etc. Some employers find it expedient to use simple eye and muscular co-ordination tests to determine the candi-

date's ability to detect the colors encountered in welding and to develop an automatic control of the arc.

With adequate equipment provided, the operator may be instructed in the following subjects:

1. Manipulation of the arc.
2. Characteristics of the arc.
3. Characteristics of fusion.
4. Thermal characteristics.
5. Welding procedure.
6. Inspection.

Arc Manipulation.—A sitting posture which aids in the control of the arc is shown in Fig. 36. It should be noted that

Fig. 36.—Correct Welding Posture and Equipment.

by resting the left elbow on the left knee the communication of body movements to the welding hand is minimized, while by supporting the electrode holder with both hands the arc may be readily directed. During the first attempts to secure arc control covered electrodes may be used, as these greatly increase arc stability, permitting the welder to observe arc characteris-

ties readily. It is suggested that throughout the training period the instructor give frequent demonstrations of the welding operations as well as occasionally guide the apprentice's welding arm.

Arc Formation.—With the welding current adjusted to 100 amp. and a $^5/_{32}$-in. covered electrode in the holder, the operator assumes the posture shown and lowers the electrode until contact is made with a mild-steel plate on the welding table, whereupon the electrode is withdrawn, forming an arc. If an insulating film covers either electrode surface or the current adjustment is too low, no arc will be drawn. With the arc obtained the operator should note the following characteristics of arc manipulation.

Fusion of Electrodes.—The fusion of electrodes is frequently called "sticking" or "freezing." It is the first difficulty encountered and is caused either by the use of an excessive welding current or by holding the electrodes in contact too long before drawing the arc. This fusing tendency is always present because the welding operation requires a current density high enough to melt the wire electrode at the arc terminal. When such fusion occurs the operator commits the natural error of attempting to pull the movable electrode from the plate. If he succeeds in separating the electrodes, the momentum acquired, unless he is very skillful, is sufficient to carry the electrode beyond a stable arc length. If, however, the wrist of the welding hand is turned sharply to the right or left, describing the arc of a circle having its center at the electrode end, the fused section is sheared and a large movement of the electrode holder produces an easily controllable separation of the arc terminals.

Maintenance of Arc.—After forming the arc the chief concern of the welder should be to maintain it until most of the electrode metal has been deposited. If the movable electrode were held rigidly, the arc would gradually lengthen as the electrode end melted off until the arc length had increased sufficiently to become unstable and interrupt the flow of current. To maintain a constant stable arc length it is necessary for the operator to advance the wire electrode toward the plate at a rate equal to that at which the metal is being deposited. For the novice this will prove quite difficult. However, if the

initial attempts are made with covered electrodes, which permit greater arc-length variations than bare electrodes, the proper degree of skill is soon acquired.

When the operator succeeds in maintaining a short arc length for some time, the covered electrode should be replaced by a $^5/_{32}$-in. diameter bare electrode, the welding current increased to 150 amp. or 175 amp. and either reactance included in the circuit or the voltage of the welding set increased. With increase in manipulative skill the reactance coil may be short-circuited or the supply voltage reduced to normal and practice continued under commercial circuit and electrode conditions.

Further instruction should not be given until the candidate is able to maintain a short arc during the entire period required to deposit the metal from a bare electrode 14 in. long, $^5/_{32}$ in. in diameter, on a clean plate $\frac{1}{2}$ in. in thickness when using a welding current of 150 amp. The arc voltage may be used as a measure of the arc length. The average arc voltage during the test should be less than twenty-five, as this corresponds to a length of approximately $\frac{1}{8}$ in. Some operators meet this test in the first hour of their training, others require two or three days' practice. If arc-length control is not obtained within the latter period, the instructor may safely conclude that the apprentice is physically unfitted for the occupation of arc welding. If the test is satisfactory, training should be continued, using bare electrodes but with such stabilizing means as inductance or resistance again inserted in the circuit.

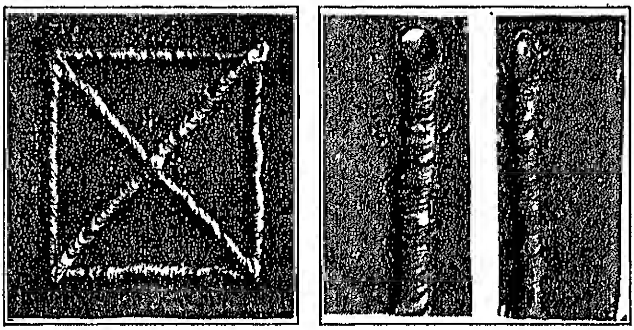
Control of Arc Travel; Direction and Speed.—The plate arc terminal and the deposited metal follow the direction taken by the pencil electrode. The difficulty of forming deposits varies with the direction. The first exercise should consist in forming a series of deposits in different directions, as shown in A, Fig. 37, until the operator develops the ability to form a series of straight, smooth-surfaced layers. Additional skill may be acquired by the practice of forming squares, circles and initials.

The speed of arc travel determines the height of the deposit above the parent metal. A second exercise should require the formation of deposit strips having heights of $^1/_{16}$, $^1/_8$ and $^3/_{16}$ in. The normal height of a deposit when using a welding

current of 150 amp. and a bare electrode of $^5/_{32}$ in. diameter is approximately $\frac{1}{8}$ in.

Weaving.—If the electrode end is made to describe the arc of a circle across the direction of deposit formation, the width of the deposit may be increased without changing the height of the deposit. This weaving movement also facilitates slag flotation and insures a more complete fusion of the deposited metal to the parent metal. *B* and *C*, Fig. 37, illustrate the appearance of deposits formed with and without weaving of the electrode.

A third exercise should consist in forming layers of equal



A B C

Fig. 37.—Control of Arc Direction Exercise.

(*A*) Exercise to develop control of arc direction. (*B*) Effect of weaving electrode across direction of deposit. (*C*) Effect of not weaving. These deposits were formed with the operator and plate in the same relative position, necessitating a change in the direction of arc travel for the deposition of each layer. Note that this direction is indicated by the position of the crater terminating each strip as well as by the inclination of the scalloped surface.

heights, but having widths of $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$ and $\frac{3}{4}$ in. when using an arc current of 150 amp. and a $^5/_{32}$-in. diameter bare electrode.

As the welder should now be able to control direction, height and width of deposits while maintaining a short arc, he should be given the fourth exercise of forming tiers of parallel, overlapping layers until inspection of the surface and cross-sections of the built-up material indicates good fusion of the metal as well as absence of slag and blowholes.

Arc and Fusion Characteristics.—The arc is the welder's tool. Its function is to transform electrical energy into highly

concentrated thermal energy. This concentrated energy serves to melt both the parent and the deposited metals at the electrode terminals, the arc conveying the liquefied pencil into the crater formed on the material to be welded.

The plate arc terminal will always appear as a crater if a welding current is used. This crater is formed partly by the rapid volatilization of the liquefied material and partly by the expulsion of fluid metal due to the explosive expansion of occluded gases suddenly released or of gases formed by chemical reaction between electrode materials and atmospheric gases. To secure good fusion the deposited metal should be dropped into the crater. This is facilitated by the use of a short arc. On welding, the operator should frequently note the depth of arc crater and manipulate the arc so that the advancing edge of the crater is formed on the parent metal and not on the hot deposited metal.

Polarity.—When using bare electrodes the concentration of thermal energy is greater at the positive than at the negative terminal. Since in most welding applications the joint has a greater thermal capacity than the pencil electrode, more complete fusion is assured by making the former the positive electrode. The difference in concentration of thermal energy may be readily illustrated to the welder by having him draw an arc from a $^1/_{16}$-in. thick plate with the plate first connected to a negative and then to the positive terminal. If a current of approximately 60 amp. is used with a $^1/_{16}$-in. diameter electrode, he will be able to form a deposit on the plate, if the plate is the negative terminal. On reversing the polarity, however, the energy concentration will be sufficient to melt through the plate, thus producing a "cutting arc."

An arc stream consists of a central core of electrically charged particles and an envelope of hot gases. The electrode material is conveyed in both liquid and vapor form across the arc, a spray of small globules being discernible with some types of electrodes. Since atmospheric gases tend to diffuse through this incandescent metal stream, it is obvious that some of the conveyed material becomes oxidized.

Through the maintenance of a short arc, not exceeding $\frac{1}{8}$ in., the resulting oxidation is a minimum because enveloping oxide of manganese vapor and carbon dioxide gas, formed by

the combination of atmospheric oxygen with the manganese and carbon liberated from the electrodes, serves as a barrier to restrict the further diffusion of atmospheric gases into the arc stream. Fig. 38 illustrates the degree of protection afforded the conveyed metal when using short and long arcs. With the latter convection currents deflect the protecting envelope from the arc stream. The effect of arc length on rate of oxidation may be clearly indicated to the welder by forming deposits with a $\frac{1}{8}$-in. arc and a $\frac{3}{8}$-in. arc on a clean plate.

The surface of the first deposit will be clean and smooth, as shown at *a*, Fig. 39. The surface of the second deposit will be irregular and covered with a heavy coating of iron oxide, as shown at *b*. All oxide formed during welding should be

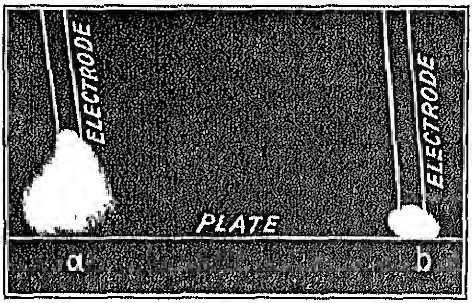


FIG. 38.—Long and Short Welding Arc.
Large arc stream causes excessive oxidation.

floated to the surface, since its presence in the weld will reduce the strength, ductility and resistance to fatigue of the joint.

Stability.—The ease of maintaining an arc is determined by the stabilizing characteristics of the electrical circuit and the arc gases. As noted above, increased stability may be obtained by the use of series inductance or higher circuit voltage with increased series resistance, higher arc currents and covered electrodes. A high-carbon-content electrode, such as a drill rod, gives a less stable arc than low-carbon content rods, owing apparently to the irregular formation of large volumes of arc-disturbing carbon-dioxide gas. Bare electrodes after long exposure to the atmosphere or immersion in weak acids will be found to "splutter" violently, increasing thereby the difficulty of arc manipulation. This "spluttering" is apparently caused

by irregular evolution of hydrogen. If the electrode is coated with lime, its stability improves.

The evident purpose of a welding process is to secure fusion between the members welded. The factors that determine fusion in arc welding are arc current, electrode current density, thermal capacity of joint sections and melting temperatures of electrode and plate materials. By observing the contour of the surface of the deposited metal as well as the depth of the arc crater the welder may determine at once whether such conditions under his control as arc current, electrode current

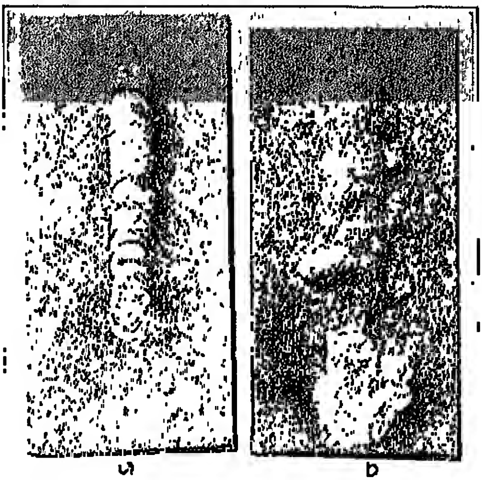


FIG. 30.—Deposit Obtained with Short Arc and Long Arc.

Note that surfaces of deposit and plate in (*a*) are comparatively clean, while those in (*b*) are heavily coated with iron oxide.

density and electrode material are properly adjusted to produce fusion.

The fifth exercise should consist of forming a series of deposits with arc currents of 100, 150 and 200 amp., using electrodes with and without coatings having different carbon and manganese content. Cross-sections of the deposits should then be polished and etched with a 10 per cent nitric-acid solution and the surface critically examined for such evident fusion characteristics as penetration and overlap, comparing these with the surface characteristics.

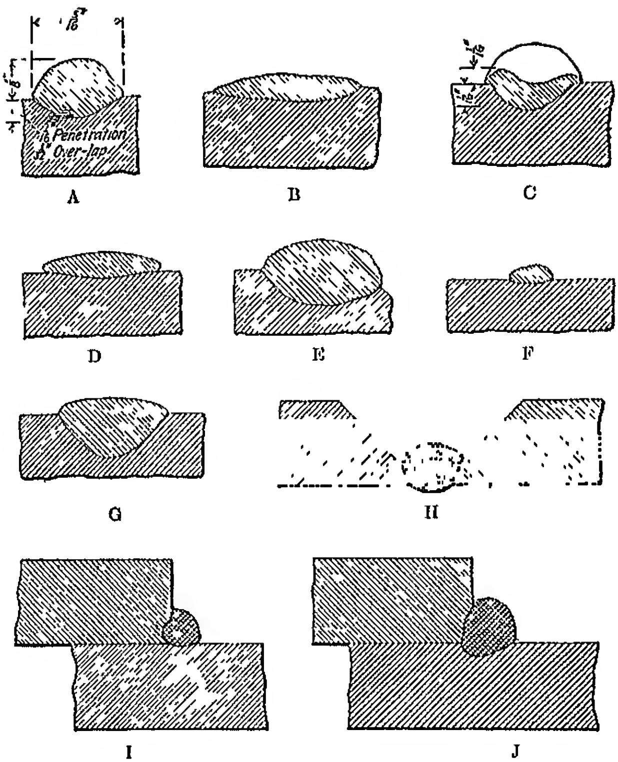


FIG. 40.—Overlap and Penetration Studies.

(*A*) Typical section through a normal layer formed by depositing metal from a mild steel electrode on a mild steel plate. Note the contour of the deposit as well as that of the fused zone and the slight overlap and correct depth of deposit penetration. Parent metal crystal structure is altered by thermal changes.

(*B*) Typical section through a deposit formed when holding a long arc. Excessive overlap and no penetration exist. Most weld failures may be attributed to the operator maintaining occasionally or continuously too long an arc.

(*C*) Section through crater formed on completing deposit strip. The depth of the crater is a measure of the depth of penetration.

(*D*) Excessive overlap secured with a pencil electrode (drill rod) having a lower melting temperature than the parent metal (mild steel).

(*E*) Elimination of overlap obtained by using a pencil electrode (mild steel) having a higher melting temperature than the parent metal (cast iron).

(*F*) Incomplete fusion obtained with a low arc current.

(*G*) "Cutting" secured through use of high arc current.

(*H*) Section indicates proper selection of welding current and electrode diameter to secure fusion.

(*I*) Poor fusion caused by too rapid flow thermal energy from deposit through plates.

(*J*) Adequate fusion obtained by increasing arc terminal energy to compensate for increased rate of heat flow.

Overlap and Penetration.—Examination of the boundary line between the deposited and plate metals in *A* and *B*, Fig. 40, reveals that the penetration decreases in both directions from the center of the layer, no fusion being evident at the edges of the deposit, the contour betraying the extent of this overlap. As shown in *C* the penetration may be estimated from the crater depression.

An exaggerated overlap obtained in welding a mild-steel plate with a high-carbon-content steel rod, having a lower melting point than the plate, is shown in *D*. The re-entrant angle of the deposit edge is plainly evident. *E* illustrates a condition of no overlap in depositing metal from a mild-steel electrode upon a cast-iron plate having a lower melting point. *F* and *G* show respectively the effect of using too-low and too-high arc currents.

The effect of heat conductivity, heat-storage capacity, expansion and contraction of the parent metal and contraction of the hot-deposit metal must be studied.

Heat Conductivity and Capacity.—The effect of any of these factors is to increase the flow of thermal energy from the plate arc terminal and therefore to reduce the amount of metal liquefied. To maintain a given rate of welding speed it therefor becomes necessary to increase the arc current with increase in thickness or area of joint.

A welding current of 150 amp. will produce satisfactory penetration on welding the apex of scarfed plates ½ in. thick shown in *H*. If the joint is backed by a heavy steel plate, increasing thereby both its thermal capacity and conductivity, a higher current, in the neighborhood of 175 amp. to 200 amp., will be required for the same penetration. If a lap joint is made as in *I* and the same current used as in *H*, the flow of heat will be so rapid that poor fusion will result. By increasing the current to 225 amp., *J*, the desired penetration, as indicated by crater depth, will be obtained with the maintenance of a high welding speed.

Expansion and Contraction of Parent Metal.—The welding operation necessarily raises the temperature of the metal adjacent to the joint, producing strains in the structure if it does not expand and contract freely. This condition is particularly marked when welding a crack in a large sheet or plate. The

plate in the region of the welded section expands, the strains produced react on the cold metal at the end of the crack to open it further, with the result that as the welding proceeds the plate continues to open at a rate about equal to the welding speed. One inexperienced welder followed such an opening for 7 ft. before adopting preventive measures. The simplest of these is to drill a hole at the end of the crack and follow an intermittent welding procedure which will maintain the plate at a low temperature. Under exceptional conditions, such as welding cracks in heavy cast-iron plates or cylinders, it is advisable to preheat and anneal the regions stressed. A second example is offered by the warping obtained on building up the diameter of a flanged shaft. The face of the flange adjacent to the shaft becomes hotter than that opposite, producing internal stresses which warp the flange to a mushroom shape. Preheating of the flange will prevent this.

Contraction of Deposited Metal.—The contraction of deposited metal is the most frequent cause of residual stress in welds and distortion of the members welded. The magnitude of "locked-in" stresses depends upon the welding procedure and the chemical constituents of parent and deposited metals. If the deposit is thoroughly annealed, practically no stress will remain. On adopting a welding sequence in which the joint is formed by running tiers of abutting layers, each newly applied layer will serve partly to anneal the metal in adjacent layers. If mild-steel plate, with less than 0.20 per cent carbon, is welded in this way, the locked-in stresses should be less than 5,000 lb. per square inch. With increase in carbon content the locked-in stresses will increase. If welded joints of high-carbon steels are not permitted to cool slowly, they will often fall apart when the joint is given a sharp blow.

To illustrate this characteristic, the following exercises are suggested:

Exercise 1—Deposit a layer 1 ft. long on a strip of steel about $^3/_{16}$ in. thick, $^1/_2$ in. wide, using 150 amp. direct current and a $^5/_{32}$-in. bare electrode. The longitudinal contraction of the deposit will bend the strip of metal as shown in Fig. 41.

Exercise 2—Deposit a layer of metal around the periphery of a wrought-iron tube. The contraction of the deposit will cause the tube to decrease in diameter.

Exercise 3—Place two plates, ½ in. thick, 2 in. wide, 6 in. long, ⅛ in. apart, and deposit a layer of metal joining them together. The transverse contraction on cooling will pull the plates out of line.

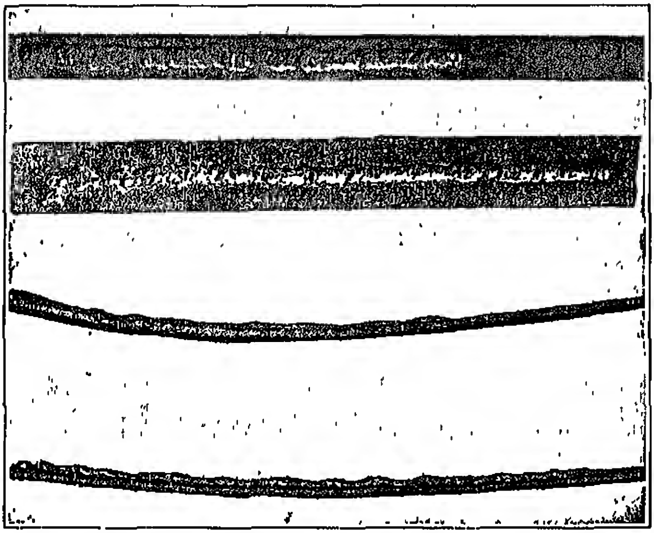


FIG. 41.—Warping of the Parent Metal Caused by the Transverse Contraction of the Deposited Layers.

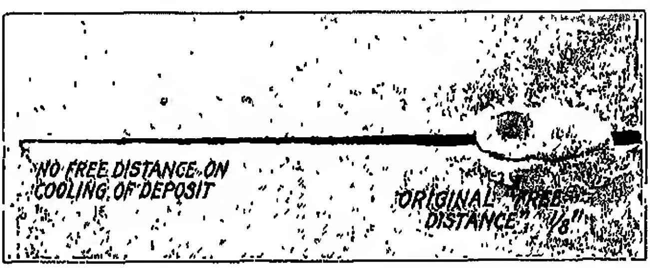


FIG. 42.—Reduction of "Free Distance" Caused by Transverse Contraction.

Illustrates the necessity of rigidly clamping the joint members, or of assembling them by an increasing distance from the end to be first welded, to equalize the movement caused by the contraction of the deposited metal, if the desired "free distance" is to be maintained throughout the welding operation.

Exercise 4—If two plates, ¼ in. thick, 6 in. wide and 6 in. long, spaced ⅛ in., are welded by depositing a short layer extending ¼ in. from the one end, it will be found that when

the deposit has cooled the resulting transverse contraction will not only warp the plates as in Exercise 3, but will also draw them together as shown in Fig. 42, thereby decreasing the free distance between plates.

Welding Procedure.—Satisfactory welds will be obtained only when the sections to be welded are properly scarfed or cut out and the surfaces on which the deposits are formed cleaned before and during the welding operation. The scarfs may be machined or cut with a cold chisel or the carbon arc. The surfaces of the deposited layers may be cleaned with a

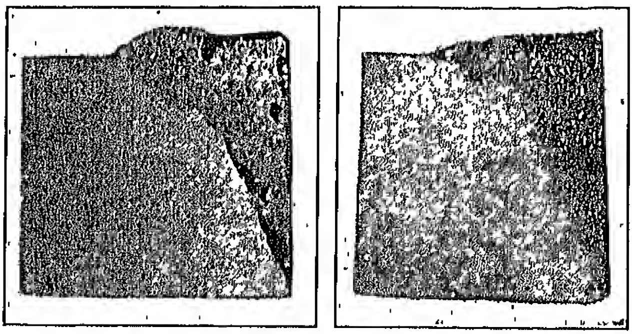


Fig. 43.—Welds Showing Poor and Good Fusion.

Section through one-half of a welded joint showing poor fusion obtained at apex of V as the result of assembling the joint sections without a "free distance." Section through one-half of a welded joint showing excellent fusion obtained as a result of the use of a "free distance" of ⅛ in., thus permitting the operator to maintain a short arc when welding the bottom of the V. Failures of deep welds may be usually attributed to the use of too small a "free distance," low welding current, improper cleaning of scarf faces or incomplete slag flotation.

chisel or wirebrush, although the use of a sandblast is preferable. The joint sections should be separated by a free distance of about ⅛ in. in order that the bottom of the V may be accessible to the welder.

The scarf angle and free distance vary inversely. Both are determined by the depth of the V. If the character of the work is such that it is not practicable to separate the joint sections, the V should be cut at the bottom to form a 90-deg. angle, this angle being reduced to 60 deg. as the surface is approached; otherwise the scarf angle may be reduced along the entire length to 60 deg., excepting in the case of very deep

welds. It is usual practice now to scarf plate welds to 60 deg. and separate the sections $\frac{1}{8}$ in. for V's up to $\frac{1}{2}$ in. in depth.

At the left in Fig. 43 is shown the poor fusion obtained at the bottom of the V on welding a 1-in. square bar, scarfed 60 deg., without the use of a free distance. At the right is shown the satisfactory union obtained with the use of free distance of $\frac{1}{8}$ in. Whenever a butt joint is accessible to horizontal welding from both sides, it is preferable to scarf the sections to a double-bevel, double-V joint.

The choice of arc current is determined by the thermal conductivity and capacity of the joint as previously discussed, a convenient criterion being the depth of arc crater. The arc current selected should be of such a value that on welding the given sections the depth of the arc crater or "bite" is never less than $^1/_{16}$ in.

Electrode Current Density.—To maintain a uniform flow of the metal, neither too slow, which causes excessive penetration, nor too fast, which produces excessive overlap, an electrode diameter should be chosen such that the current density is approximately 8,000 amp. per square inch. For the usual sizes of bare wire available this corresponds to the following welding currents:

Arc Current (Amp.)			Electrode
Normal	Maximum	Minimum	Diameter (in.)
225	275	190	3/16
155	190	125	5/32
100	125	70	1/8
60	70	45	3/32

If covered electrodes are used, the direct-current rating for the wires should be decreased roughly to 60 per cent of these values. If bare wires are used on alternating current, the rating should be increased from 20 to 40 per cent.

The first layer should thoroughly fuse the apex of the V. Wherever possible inspect the reverse side, as the deposited metal should appear projecting through. Subsequent layers should be fused then to the preceding layers or to the scarfed face. The final surface should be from $^1/_{16}$ to $^1/_8$ in. above that of the adjacent sections. This welt increases the strength of the joint or permits the joint surface to be machined to a smooth finish. If the weld is to be oil-tight, the metal project-

ing through the abutting sections on the reverse side as a result of the first step in filling the section should be chipped out and the resulting groove filled with at least one layer of deposited metal. This extension of the procedure is frequently used in the welding of double-bevel joints where the joint is to have a "100 per cent" strength.

If a vertical seam is to be welded, sufficient material should first be deposited to produce a shoulder so that the added metal may be applied on an almost horizontal surface to facilitate the welding operation.

If an overhead seam is to be welded, the operation is simplified by placing on the upper side of the joint a heavy steel plate covering the apex of the V. A shoulder is then formed by an initial deposit of metal, the operator continuing to add metal to the corner so produced and the vertical face of the shoulder.

The considerations pointed out under the section on thermal characteristics determine whether it is necessary to preheat and anneal the joint. The method used in filling the scarfed section is determined by the preference for either the rigid or non-rigid system.

When using the rigid system both sections of the joint are clamped firmly to prevent either member from moving under the stresses produced by the expansion and contraction obtained during the welding operation. If a proper welding sequence is not followed, the accumulation of "locked-in" stresses on cooling may be sufficient to rupture the welded area. To minimize these stresses it is the usual practice to tack the plates together at the apex of the scarf with short deposits at about 1-ft. intervals, and then to deposit single layers in alternate gaps, each tier being completed before adding a second tier at any section. This procedure tends to maintain a low average temperature of the joint and plate, thereby decreasing the amount of expansion, while the deposition of the metal in layers serves partly to anneal the metal beneath and materially reduce "locked-in" stresses.

In the non-rigid system both members of the joint are free to move. To prevent the edges of the plate from overlapping or touching as shown in Fig. 42, the initial free distance is made great enough to equalize the movement of the plates caused

by the contraction of the hot deposited metal. On welding long seams of ½-in. plate the contraction is limited by maintaining a spacing block $^5/_{16}$ in. wide, approximately 1 ft. ahead of the welded section. With a "free distance" of ⅛ in. the contraction stresses draw the plates together a distance of $^3/_{16}$ in. This modification converts the non-rigid into a semi-rigid system.

Inspection.—No direct, non-destructive means are available for readily determining the strength and ductility of welds. A number of indirect methods, however, are in commercial use which give a fair measure of weld characteristics if intelligently applied. They consist in estimating the degree of fusion and porosity present by critically inspecting the surface of each layer and in noting the depth of liquid penetration through the completed section.

In examining each layer the amount of oxide present, smoothness and regularity of the surface, its contour, freedom from porosity and depth of crater should be noted. After a little experience these observations will give the inspector a good indication of the manipulative ability of the welder and of the degree of fusion obtained, as discussed above.

A succession of unfused zones will produce a leaky joint. These sections may be detected by flooding one surface of the joint with kerosene, using a retaining wall of putty, if necessary, as the liquid penetrates through the linked areas and emerges to stain the opposite side.

Brief Terminology.—The following terms are used most frequently in arc welding:

Free distance.—The amount that the joint sections are separated before welding.

Overlap.—The area of deposited metal that is not fused to the parent metal.

Parent metal.—The original metal of the joint sections.

Penetration.—The depth to which the parent metal is melted by the arc—gaged by the depth of the arc crater.

Recession.—The distance between the original scarf line and the average depth of penetration parallel to this line obtained in the completed weld.

Re-entrant angle.—The angle between the original surface of the parent metal and the overlapping, unfused deposit edge.

Scarf.—The chamfered surface of a joint.

Tack.—A short deposit, from ½ to 2 in. long, which serves to hold the sections of a joint in place.

Weaving.—A semi-circular motion of the arc terminal to the right and left of the direction of deposition, which serves to increase the width of the deposit, decrease overlap and assist in slag flotation.

Welt.—The material extending beyond the surface of the weld shanks to reinforce the weld.

Questions and Answers

What does the welder's equipment consist of?

Welding generator, electrode holder with cables, welding booth, helmet or shield, gauntlets, high shoes with bellows tongue, heavy clothing or leather apron, proper electrodes.

What is the most important precaution the operator should observe?

To protect his eyes and body from the radiant energy emitted by the arc.

How is the operator prevented from drawing too long an arc after the electrode "freezes" to the work?

By twisting the wrist sharply to the right or left, thereby shearing the fused area.

What is the essential factor in securing the maintenance of the arc?

The electrode should be advanced to the work at the rate at which it is being melted.

What is the test of an operator's manipulative ability?

He should be able to hold an arc no longer than ⅛ in., having a voltage across it less than twenty-five during the period required to deposit the metal from a $^5/_{32}$-in. diameter bare electrode, 12 in. long on 150 amp. direct current.

What is meant by "free distance," "overlap," "parent metal," "penetration," "recession," "re-entrant angle," "scarf," "tack," "weaving" and "welt"?

Given under "Terminology."

What function does the arc perform?

It transforms electrical energy into Thermal energy.

What polarity should the welder use on welding all but thin sections with bare electrodes?

The pencil electrode should be negative.

How may the amount of oxide formed be reduced to a minimum?

By holding a short arc and the use of electrodes containing a small quantity of carbon (0.18 per cent) and manganese (0.50 per cent).

How may an operator determine the degree of fusion obtained (a) by inspecting the surface, (b) by inspecting the cross-section of deposit?

(a) By examining the contour of the surface, noting the re-entrant angle and estimating the overlap; observing the depth of crater and estimating the penetration.

(b) By directly observing the depth of penetration of recession, the overlap and porosity or blow holes.

What are the factors in arc welding that determine the degree of fusion?

Arc current, arc length, electrode current density, electrode material, freedom of weld from oxides.

How may a welder determine when he is using the proper welding current?

By the depth the arc melts the material welded. The crater should be not less than $^1/_{16}$ in. in depth.

What is the most important thermal characteristic encountered in welding?

Contraction of the hot deposit.

How may strains produced by this characteristic be minimized?

By adopting a correct welding procedure, either non-rigid or rigid, which serves partly to anneal the metal and reduce "locked-in" stresses.

What is the effect of holding too long an arc with the metallic electrode?

The use of a long arc produces a poor deposit, due to insufficient penetration, and also produces a large amount of oxide which reduces both the strength and ductility of the joint.

What size of bare electrodes corresponds to welding currents of approximately 225, 155, 100 and 60 amp. on welding with direct current?

Sizes $^3/_{16}$, $^5/_{32}$, $^1/_8$ and $^3/_{32}$ in. respectively.

How should joint sections be prepared for welding?

The surfaces should be cleaned thoroughly and the faces of the joint scarfed to an angle of 60 to 90 degrees with the edges separated a free distance of approximately $\frac{1}{8}$ in. in the rigid welding process, and an additional $^3/_{16}$ in. per foot from the point welded for each foot length when using the non-rigid system.

What surface characteristics denote fusion?

Surface porosity, amount of oxide coating, depth of arc crater, surface contour, compactness, regularity and re-entrant angles.

CHAPTER V

CARBON-ELECTRODE ARC WELDING AND CUTTING

In the *American Machinist* of Sept. 9, 1920, O. H. Escholz, research engineer of the Westinghouse Electric & Manufacturing Co., dealt with the various phases of carbon arc welding and cutting as follows:

Carbon or graphite electrode arc welding is the oldest of the electric fusion arc processes now in use. The original process consisted in drawing an arc between the parent metal and a carbon electrode in such a manner that the thermal energy developed at the metal crater fused together the edges of the joint members. This process was early modified by adding fused filling metal to the molten surface of the parent metal.

The equipment now used consists of a direct-current arc-circuit possessing inherent means for stabilizing the carbon arc, a welding hood for the operator, an electrode holder that does not become uncomfortably hot in service and suitable clothing such as bellows-tongued shoes, gauntlets and apron of heavy material.

When arc currents of less than 200 amp. are used, or when a graphite arc process is employed intermittently with the metallic electrode process, the carbon-holding adapter shown in Fig. 44 may be used with the metallic electrode holder, the shank of the adapter being substituted for the metal electrode. With very high arc currents, 750 amp. or more, special holders should be constructed to protect the operator from the intense heat generated at the arc. Typical holders are shown in Figs. 45 and 46.

Electrodes.—Although hard carbon was originally employed for the electrode material, experience has shown that a lower rate of electrode consumption as well as a softer weld may be obtained by substituting graphite electrodes. While both elec-

trodes have the same base and binder, the graphite electrode is baked at a sufficiently high temperature (2000 deg. C.) to graphitize the binder, thereby improving the bond and the homogeneity of the electrode. The graphite electrode is readily

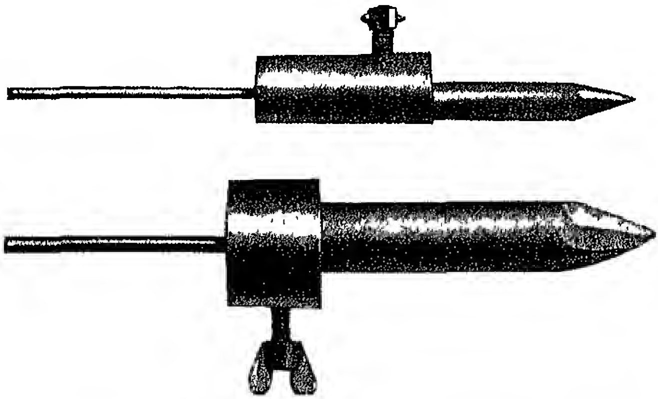


FIG. 44.—Adapters for Using Carbons in Metallic-Electrode Holder

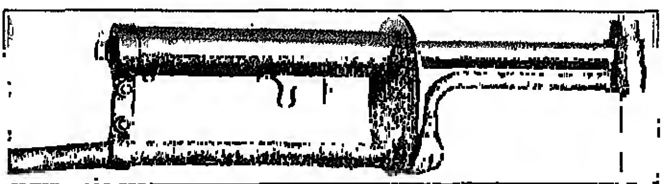


FIG. 45.—Metallic-Electrode Holder.

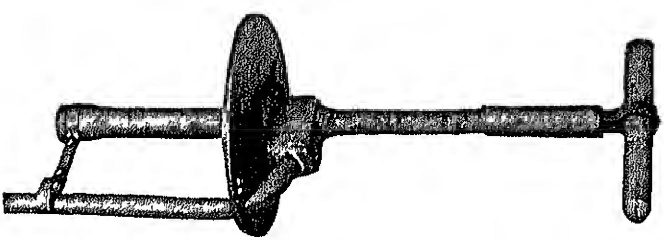


FIG. 46.—Carbon- or Graphite-Electrode Holder.

distinguishable by its greasy "feel" and the characteristic streak it makes on paper.

The diameter of the electrode is determined partly by the arc current. To fix the position of the carbon arc terminal,

thereby increasing arc stability and arc control, all electrodes should be tapered. This precaution is particularly important when using low value of arc current or when maintaining an arc under conditions which cause distortion and instability. The following table gives electrode diameters in most common use with various arc currents:

Amperes	Diameter
50 to 150	$\frac{1}{2}$ in. tapered to $\frac{3}{8}$ in.
150 to 300	$\frac{5}{8}$ in. tapered to $\frac{3}{8}$ in.
300 to 500	1 in. tapered to $\frac{3}{8}$ in.
500 to 750	$1\frac{1}{4}$ in. tapered to $\frac{3}{8}$ in.
750 to 1000	$1\frac{1}{2}$ in. tapered to $\frac{3}{8}$ in.

Filler Material.—A strong, sound weld can be obtained only by using for filler metal low-carbon, commercially pure iron rods having a diameter of $\frac{3}{8}$ in. or $\frac{1}{2}$ in., depending on the welding current used. Cast iron or manganese steel filler rods produce hard welds in which the fusion between the parent and added metals may be incomplete. Short rods of scrap metal, steel turnings, etc., are frequently made use of for filler metal when the purpose of the welder is merely to fill a hole as rapidly as possible. It should be understood that welds made with such metal are weak, contain many blowholes and are frequently too hard to machine.

It is as difficult for the user of graphite arc processes as it is for the oxy-acetylene welder to estimate the degree of fusion obtained between deposited and parent metals. Therefore the operator must follow conscientiously the correct procedure, recognizing that the responsibility of executing a faulty weld rests solely with himself. He should, of course, have a working knowledge of metals, must be able to distinguish colors and possess a fair degree of muscular co-ordination, although the manipulative skill required is less than that necessitated by the metallic electrode process.

For graphite arc welding employing a filler the correct posture is illustrated in Fig. 47. The filler rod is shown grasped by the left hand with the thumb uppermost. When held in this position the welder may use the rod to brush off slag from the surface of molten metal or to advance the rod into the arc stream.

The surfaces to be welded should be chipped clean. Where

they are scarfed the angle should be wide enough to enable the operator to draw an arc from any point without danger of short-circuiting the arc. It is the practice of some welders to remove sand and slag from the metal surfaces by fusing them with the aid of the arc and then striking the fluid mass with a ball-peen hammer. This method should be discouraged since both operator and nearby workmen may be seriously injured by the flying hot particles.

Arc Manipulation.—The arc is formed by withdrawing the graphite electrode from a clean surface of solid metal or from the end of the filler rod when it is held in contact with the

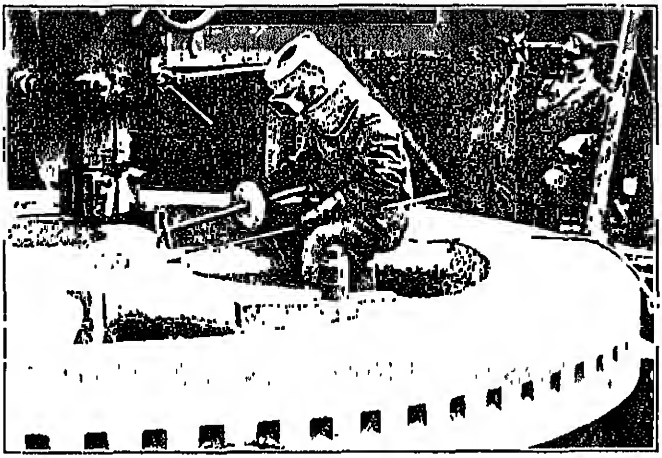


FIG. 47.—Correct Welding Position when Using Carbon Arc and a Filler Rod.

parent metal. If the arc is formed from the surface of the deposited metal or from that of a molten area, slag particles may adhere to the end of the electrode, deflecting the arc and increasing the difficulty of manipulating it.

By inclining the electrode approximately 15 deg. to the vertical the control of the position, direction and speed of the arc terminal is facilitated. When the electrode is held vertically irregularities in the direction and force of convection currents deflect the arc first to one side and then to another, causing a corresponding movement of the metal arc terminal. By inclining the graphite electrode the deflecting force is constant in direction, with the result that the electrode arc stream

and arc terminal remain approximately in line, as shown in Fig. 48, and may then be moved in any direction or at any speed by a corresponding movement of the graphite electrode.

Polarity.—It is common knowledge that the positive terminal of a carbon arc is hotter and consumes more energy than the negative terminal. If the graphite electrode of the welding arc is made the positive terminal, energy will be use-

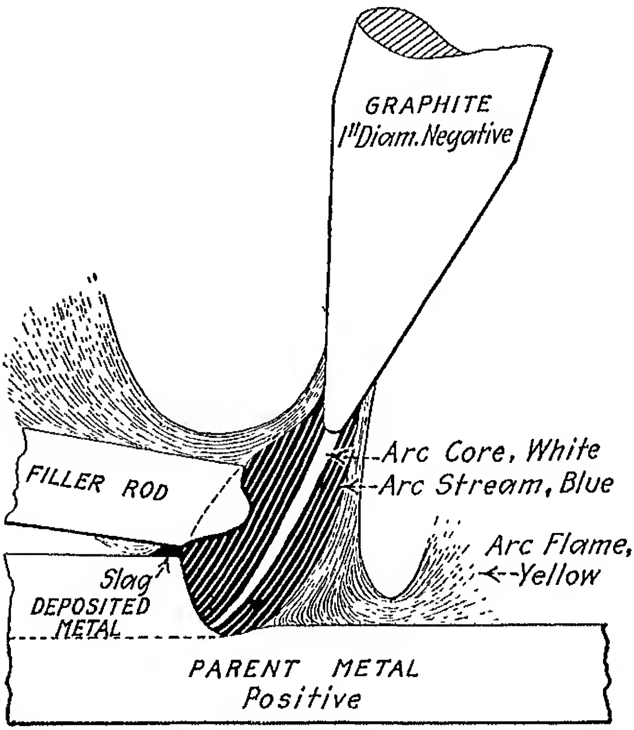


Fig. 48.—Position of Electrode and Characteristics of the Arc.

lessly consumed and the resulting higher temperature will increase the loss of carbon through excessive oxidation and vaporization. Moreover, for reasons well known to those familiar with the phenomena of arc formation, a very unstable arc is obtained with the iron parent metal functioning as the negative electrode. The graphite electrode should therefore always be connected to the negative terminal, reversal of

polarity being detected when the arc is difficult to hold and when the carbon becomes excessively hot.

Arc Length.—Even when the graphite electrode serves as the negative arc terminal, its temperature is great enough to cause vaporization of a considerable quantity of carbon. If this carbon is permitted to be transferred to and absorbed by the fluid metal, a hard weld will result. To insure a soft metal practically all of the volatilized carbon should be oxidized. This may be accomplished by regulating the arc length so that atmospheric oxygen will have ample time to diffuse through the arc stream and combine with all of the carbon present. The correct arc length is dependent upon the welding current and the degree of confinement of the arc. Since the arc diameter varies as the square root of the current the arc length should be increased in proportion to the square root of the current. It is also obvious that when an arc is drawn from a flat, open surface the vaporized carbon is more accessible to the atmospheric gases than when it is inclosed by the walls of a blowhole. This means that to secure the same amount of oxidized carbon under both conditions the confined arc should be the longer. Many welders are not familiar with this phenomenon, with the result that metal deposited in holes or corners appears to be inexplicably hard.

The length of a 250-amp. arc should not be less than ½ in. and that for a 500-amp. arc should not be less than ¾ in. when drawing the arc from a flat surface. The maintenance of excessive arc lengths causes the diffusion, through convection currents, of the protecting envelope of carbon dioxide, with the result that the exposed hot metal is rapidly oxidized or "burned." For most purposes a 250-amp. arc should not exceed a length of 1 in. and the length of a 500-amp. arc should not exceed 1½ in. In view of the large variation permissible, the welder should be able to maintain an arc length which assures a soft weld metal with but little slag content.

The arc serves to transform electrical energy into thermal energy. The energy developed at the metal terminal or arc crater is utilized to melt the parent metal, while that generated in the arc stream serves to melt the filling material. If the molten filler is not properly guided and, as a consequence, overruns the fused parent metal, a poor weld will result. This

process necessitates, therefore, a constant observation of the distribution of the fused metals as well as a proper control of the direction of flow and speed of deposition of the filling metal.

There are two methods in use for adding the filler with a

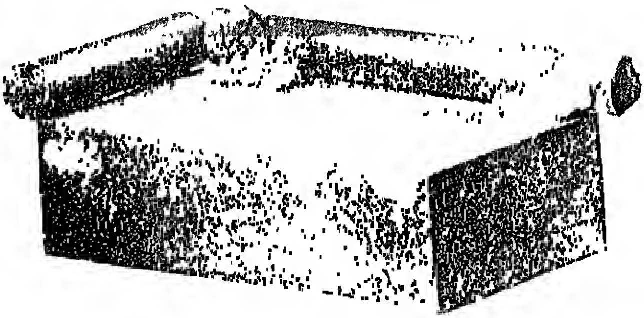


Fig. 49.—Starting to Build Up a Surface.

minimum overlap. One is called the "puddling" process. It consists in melting a small area of the parent metal, thrusting the end of the filler rod into the arc stream, where a small section is melted or cut off, withdrawing the rod and fusing the added material with the molten parent metal by imparting

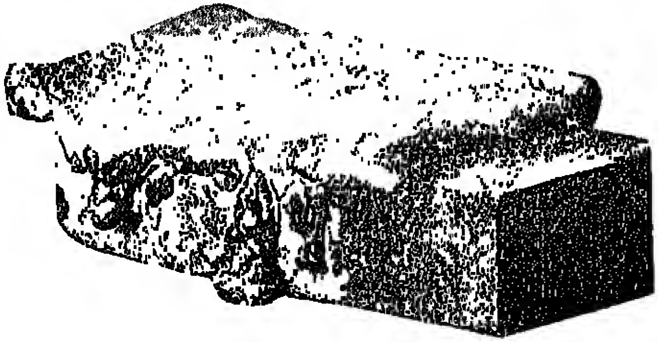


Fig. 50.—Building-Up Process Nearly Completed.

a rotary motion to the arc. This puddling of the metals serves also to float slag and oxidized material to the edge of the fused area, where they may be brushed or chipped off.

The rapid building up of a surface by this method is shown in Fig. 49. The short sections of filler rod were welded to

the sides of the casting in order to prevent the molten material from overflowing and to indicate the required height of the addition. The appearance of the nearly completed "fill" is shown in Fig. 50. One side of the added metal is lower than the others to facilitate the floating off of the slag, some of

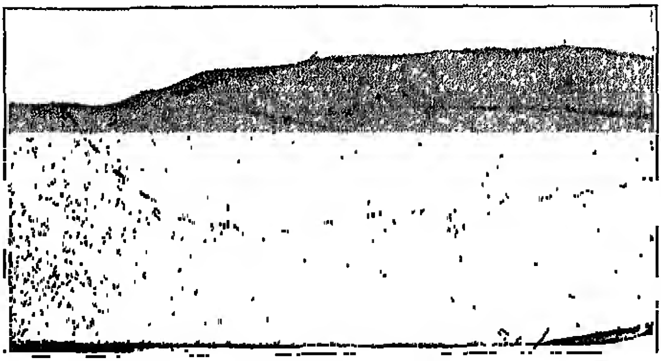


Fig. 51.—Section Through a Built-Up Weld.

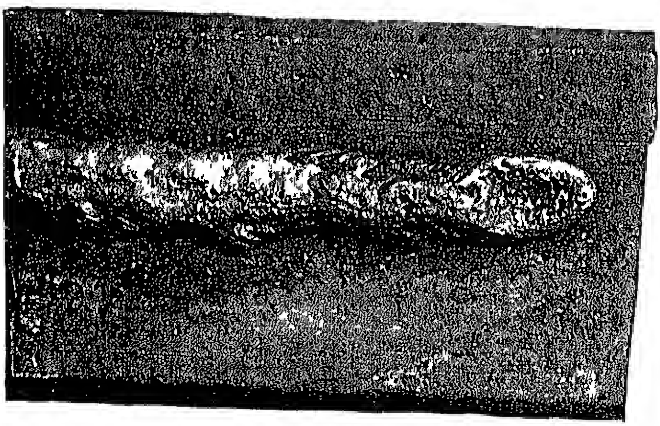


Fig. 52.—Method of Depositing Filling Material in Layers.

which may be observed adhering to the edge of the plate. Fig. 51 shows a section through a weld produced in this manner, the continuous line indicating the zone of fusion and the broken line the boundary of crystal structural change produced by the temperature cycle through which the parent metal has passed as a result of the absorption of the arc energy.

Some users of this method advocate puddling short sections of the filler rod, 1 to 3 in. in length, with the parent metal. Where this is done, the filler may be incompletely fused and therefore not welded to the surface of the parent metal.

In the second method the filler material is deposited in

FIG. 53.—Layers of Deposits Smoothed Over.

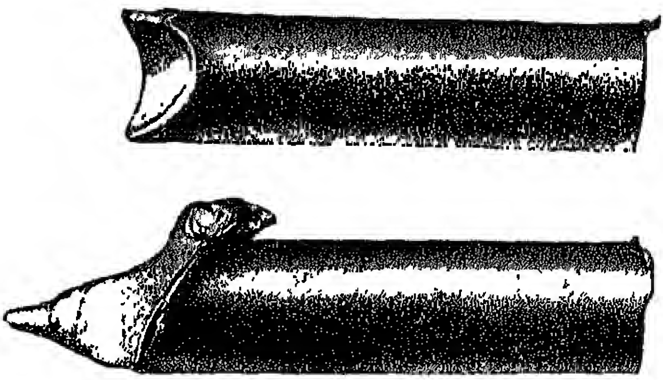


FIG. 54.—Fused Ends of Filler Rods.

layers, as shown in Figs. 52 and 53, the deposits being similar to those obtained with the metallic electrode process but wider and higher. In these examples a welding current of 250 amp. with a filling rod $\frac{3}{8}$ in. in dia. were used. This method simply requires the operator to feed the filling rod continuously into the arc stream so that the molten filler deposits on the area

of parent metal fused by the arc terminal while the arc travels across the surface. If the end of the rod is moved forward while resting on the surface of the newly deposited metal,

Fig. 55.—Showing the Fusion of Parent Metal and Four Layers.

most of the slag produced by the oxidation of the hot metal is floated to the sides of the deposit, where it may be brushed or chipped off.

The appearance of fused filler rod ends when correctly manipulated is shown in Fig. 54. Slag may be observed still

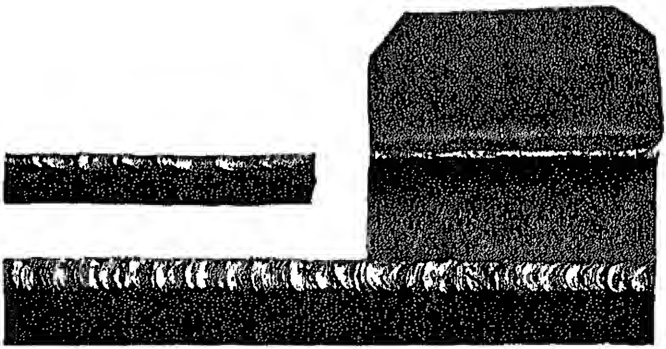


Fig. 56.—Flanged Edges Welded with Graphite Arc.

adhering to the bottom of one of the rods. The fusion between parent and added metal is shown in Fig. 55. Four layers of added metal are shown at the upper surface.

To remove slag or improve the appearance of the deposits

the surface of the added metal may be remelted by running the arc terminal over it, provided "burning" and hardening of the metal is avoided. Figs. 52 and 53 illustrate plainly the appearance of deposits before and after the surfacing operation.

The expedient of hammering or swaging the hot deposited metal is frequently resorted to where a refinement in the structure of the crystal grains is desirable.

Flanged Seam Welding.—Fig. 56 illustrates a useful application of the original carbon-arc process wherein no filler metal is used, the metal arc terminal serving to melt together the flanged edges.

This process is easily performed. To obtain adequate fusion the arc current selected should have such a value that the metal-arc crater nearly spans the edges of the seam. To assure the maintenance of a stable arc a small, tapered electrode should be employed, the diameter of the electrode end remaining less than $\frac{1}{8}$-in. during use.

This graphite arc process is used occasionally to form butt and lap welds by melting together the sides of the joint without the use of filler metal. Examination of sections through joints made in this manner reveals that the weld is very shallow and therefore weak.

Welding of Non-Ferrous Metals.—Copper and bronzes have been successfully welded with the graphite arc when employing a bronze filler rod low in tin and zinc and high in phosphorous, at least 0.25 per cent. The best filler material for the various analyses of parent metals has not been determined, but it is recognized that the presence of some deoxidizing agent such as phosphorus is necessary in order to insure sound welds free from oxide and blowholes. Since copper and its alloys have a high thermal capacity and conductivity, preheating of the structure facilitates the fusion of the joint surfaces. The grain of the completed weld may be refined by subjecting the metal to a suitable mechanical working and temperature cycle.

Low-melting-point metals such as lead may be welded by holding the graphite electrode in contact with the surfaces to be fused without drawing an arc, the current value used being sufficient to heat the end of the carbon to incandescence. The hot electrode tip may also be used to melt the filler rod into the molten parent metal.

Application.—The graphite arc processes may be used for the following purposes:

(1) Welding of cast steel and non-ferrous metals.

(2) Cutting of cast-iron and cast-steel risers and fins and non-ferrous metals.

(3) Rapid deposition of metal to build up a surface or fill in shrinkage cavities, cracks, blowholes and sand pockets where strength is of minor importance.

(4) Fusion of standing seams.

(5) Melting and cutting of scrap metal.

(6) Remelting of a surface to improve its appearance or fit.

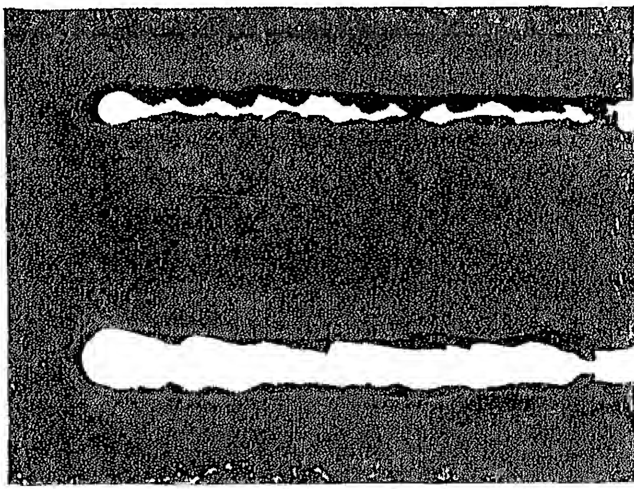


FIG. 57.—Typical Carbon-Electrode Cuts in ½-In. Ship Plate.

(7) Preheating of a metal structure to facilitate the welding operation, to reduce locked-in stresses or to alter some dimension.

(8) Deposition of hard metal or the hardening of a surface by the inclusion of vaporized carbon, such as rails, frogs and wheel treads.

(9) Automatic cutting and welding of sheet metal.

Cutting.—The manipulation of the cutting arc is exceedingly simple, the operator merely advancing the arc terminal over the section to be cut at a rate equal to that at which the molten metal flows from the cut. The cutting speed in-

creases with the value of arc current used. The width of the cut increases with the arc diameter and therefore as the square root of the arc current. Fig. 57 shows the appearance of cuts made in ship steel plate ½ in. thick. The following data apply in this case:

Position of Cut	Amp.	Width, in.	Length, in.	Time, min.
Upper	250	0.5	8	2½
Lower	650	0.8	8	1

Before cutting this plate the welder outlined the desired course of the cut by a series of prick-punch marks.

When cutting deeper than 4 in. the electrode should not come in contact with the walls of the cut and thereby short-circuit the arc.

This process may be used for cutting both ferrous and non-ferrous metals. It has found a particularly useful field in the cutting of cast iron. It is often used for the "burning" out of blast-furnace tap holes and the melting or cutting of iron frozen in such furnaces.

CUTTING METALS

The accompanying charts illustrate the application of the carbon electrode cutting process with a current value of 350 to 800 amperes, depending on the thickness of the metal and the speed of cutting desired. A moderate cutting speed is obtained at a small operating expense, adapting it particularly for use in foundries for cutting off risers, sink heads, for cutting up scrap, and general work of this nature where a smooth finish cut is not essential.

The cross section of these risers, etc., is frequently of considerable area, but by the use of the proper current value, they may be readily removed.

Table IV shows the results obtained from tests in cutting steel plate with the electric arc. The curves show the rate of cutting cast iron sections of various shapes. Fig. 58 shows the rate of cutting cast iron plates. Fig. 59 circular cross sections, and Fig. 60 square blocks. The curves are based on data secured through an extensive series of observations.

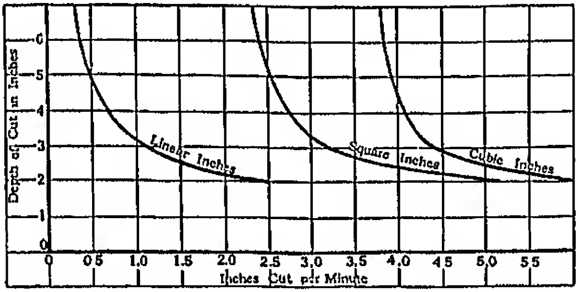


FIG. 58.—Rate of Cutting Cast Iron Plates.

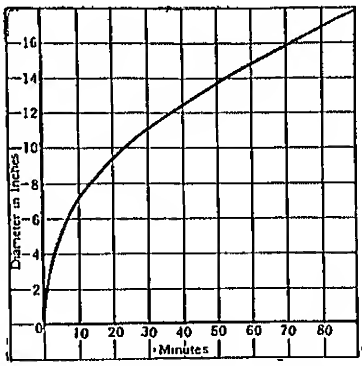


FIG. 59.—Rate of Cutting Cast Iron of Circular Cross Section.

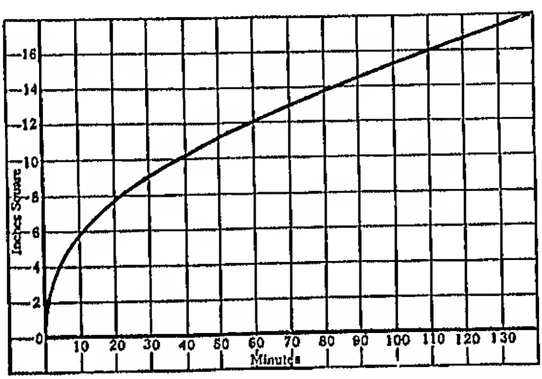


FIG. 60.—Rate of Cutting Cast Iron Square Blocks.

TABLE IV.—CUTTING STEEL PLATES WITH THE CARBON ARC

Thickness in Inches	Current in Amps.	Speed Minutes Per Ft.	Kw.-Hrs. Per Ft.
3/8	400	.50	.312
1/2	400	1.20	.75
5/8	400	2.14	1.34
3/4	400	3.00	1.88
1	600	3.75	3.50
1 3/8	600	4.32	4.10
2	600	6.75	6.30
4	600	16.00	15.50
6	800	29.00	36.20
8	800	40.50	50.00
10	800	59.00	74.00
12	800	65.00	82.00

CHAPTER VI

ARC WELDING PROCEDURE

It is presumed that the welder has a fair knowledge of the different processes of both carbon and metallic arc welding, gained from reading the previous chapters or from actual experience. However, we will recapitulate to some extent in order to make everything as clear as possible. Then we shall give some examples of the proper procedure in making welds of various kinds. For the descriptions and drawings we are principally indebted to the Westinghouse Electric and Manufacturing Co., the Lincoln Electric Co., and the Wilson Welder and Metals Co.

In order to prepare the metal for a satisfactory weld, the entire surfaces to be welded must be made readily accessible to the deposit of the new metal which is to be added. In addition, it is very essential that the surfaces are free from dirt, grease, sand, rust or other foreign matter. For this service, a sandblast, metal wire brush, or cold chisel are recommended.

During the past few years great progress has been made in the improvement of steels by the proper correlation of heat treatment and chemical composition. The characteristics of high-carbon and alloy steels, particularly, have been radically improved. However, no amount of heat treatment will appreciably improve or change the characteristics of medium and low-carbon steels which comprise the greatest field of application for arc welding. Furthermore, the metal usually deposited by the arc is a low-carbon steel often approaching commercially pure iron. It must be evident therefore that the changes of steel structure due to the arc-welding process will not be appreciable and also that any subsequent heat treatment of the medium- or mild-steel material will not result in improvements commensurate with the cost.

Pre-heating of medium and mild steel before applying the arc is not necessary and will only enable the operator to make a weld with a lesser value of current.

Cast-iron welds must be annealed before machining other than grinding is done in the welded sections. This is necessary because at the boundary between the original cast iron and the deposited metal there will be formed a zone of hard, high-carbon steel produced by the union of carbon (from the cast iron) with the iron filler. This material is chilled quite suddenly after the weld is made by the dissipation of the heat into the surrounding cast iron which is usually at a comparatively low temperature.

Although it is not absolutely necessary to pre-heat cast iron previous to arc welding, this is done in some instances to produce a partial annealing of the finished weld. The pre-heating operation will raise the temperature of a large portion of the casting. When the weld is completed, the heat in the casting will flow into the welded section, thereby reducing the rate of cooling.

Arc Length.—The maintenance of the proper arc length for the metallic electrode process is very important. With a long arc an extended surface of the work is covered probably caused by air drafts with the result that there is only a thin deposit of the new metal with poor fusion. If, however, the arc is maintained short, much better fusion is obtained, the new metal will be confined to a smaller area, and the burning and porosity of the fused metal will be reduced by the greater protection from atmospheric oxygen afforded by the enveloping inert gases. With increase in arc length, the flame becomes harder to control, so that it is impossible to adequately protect the deposited metal from oxidation.

The arc length should be uniform and just as short as it is possible for a good welder to maintain it. Under good normal conditions the arc length is such that the arc voltage never exceeds 25 volts and the best results are obtained between 18 and 22 volts. For an arc of 175 amp. the actual gap will be about $\frac{1}{8}$ inch.

Manipulation of the Arc.—The arc is established by touching the electrode to the work, and drawing it away to approximately $\frac{1}{8}$ in., in the case of the metallic electrode. This

is best done by a dragging touch with the electrode slightly out of vertical. The electrode is then held approximately at right angles to the surface of the work, as the tendency is for the heat to go straight from the end of the electrode. This assures the fusing of the work, provided the proper current and arc length have been uniformly maintained.

A slight semicircular motion of the electrode, which at the same time is moved along the groove, will tend to float the slag to the top better than if the electrode is moved along a straight line in one continuous direction and the best results are obtained when the welding progresses in an upward direction. It is necessary in making a good weld to "bite" into the work to create a perfect fusion along the edges of the weld, while the movement of the electrode is necessary for the removal of any mechanical impurities that may be deposited. It is the practice to collect the slag about a nucleus by this

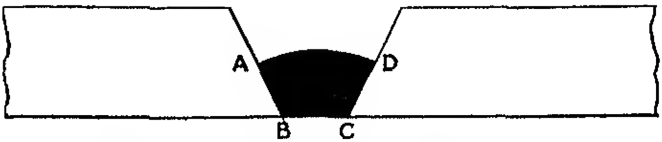


FIG. 61.—Diagram Illustrating Filling Sequence.

rotary movement and then float it to the edge of the weld. If this cannot be done, the slag is removed by chipping or brushing with a wire brush.

Filling Sequence.—When making a long seam between plates, the operator is always confronted with the problem of expansion and contraction which cause the plates to warp and produce internal strains in both plates and deposited material.

The method of welding two plates together is shown in Fig. 61. The plates are prepared for welding as previously described, and the arc is started at the point *A*. The welding then progresses to the point *B*, joining the edges together, to point *D* and back to *A*. This procedure is carried on with the first layer filling in a space of 6 or 8 in. in length, afterward returning for the additional layers necessary to fill the groove. This method allows the entire electrode to be deposited without breaking the arc, and the thin edges of the work are

not fused away as might be the case if the operator should endeavor to join these edges by moving the electrode in one continuous direction. This method also prevents too rapid chilling with consequent local strains adjacent to the weld.

When making a long seam weld, for example, a butt weld between two plates, the two pieces of metal will warp and have their relative positions distorted during the welding process, unless the proper method is used.

A method was devised and has been successfully put into operation by E. Wanamaker and H. R. Pennington, of the Chicago, Rock Island and Pacific R.R. By their method the

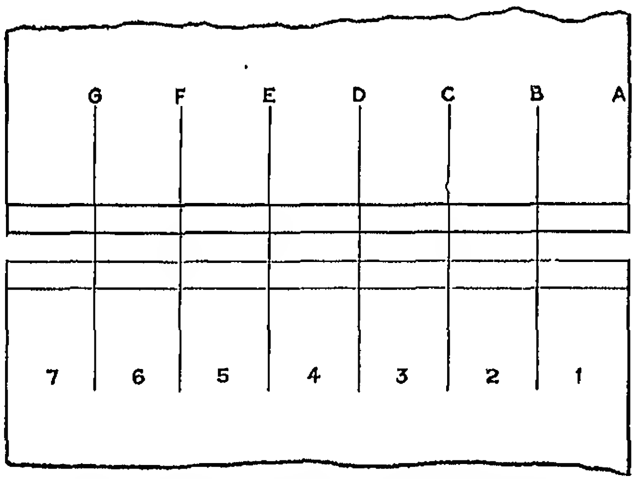


Fig. 62.—Diagram Illustrating Back-Step Method.

plates are fastened together by light tack welds about 8 in. apart along the whole seam. The operator then makes a complete weld between the first two tacks as described in the preceding paragraph, and, skipping three spaces, welds between the fifth and sixth tacks and so on until the end of the seam is reached. This skipping process is repeated by starting between the second and third tacks and so on until the complete seam is welded. The adoption of this method permits the heat, in a restricted area, to be dissipated and radiated before additional welding is performed near that area. Thus the weld is made on comparatively cool sections of the plates which keeps the expansion at a minimum.

Another method very similar to the preceding one, is known as the back-step method, Fig. 62, in which the weld is performed in sections as in the skipping process. After the pieces are tacked at intervals of 6 in. or less for short seams, the arc is applied at the second tack and the groove welded back complete to the first tack. Work is then begun at the third tack and the weld carried back to the second tack, practically completing that section. Each section is finished before starting the next.

Fig. 63 shows the procedure of welding in a square sheet or patch. Work is started at *A* and carried to *B* completely welding the seam. In order that work may next be started at the coolest point, the bottom seam is completed starting at *D*, finishing at *C*. The next seam is *A* to *D*, starting at *A*.

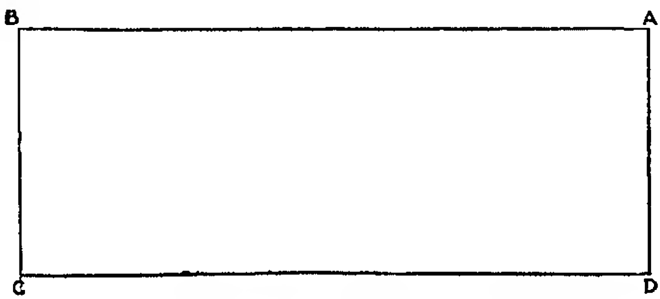


FIG. 63.—Diagram Illustrating Square Patch Method.

The last seam is finished, starting at *B*, and completing the weld at *C*.

Alternating-Current Arc Welding.—Direct current has been used for arc welding because of the fact that it possesses certain inherent advantages that make it especially adaptable for this class of work. However, the use of alternating current for arc welding has found a number of advocates.

When employing this form of energy, use is made of a transformer to reduce the distribution voltage to that suitable for application to the weld.

Inasmuch as the arc voltage is obtained directly from the distribution mains through a transformer, the theoretical efficiency is high compared with the direct-current process which requires the introduction of a motor-generator or resistor or

both. The efficiency of the a.c. equipments now on the market ranges from 60 to 80 per cent. The transformer, however, is designed to have a large leakage reactance so as to furnish stability to the arc, which very materially reduces its efficiency when compared with that of the standard distribution transformer used by lighting companies.

It is difficult to maintain the alternating arc when using a bare electrode though this difficulty is somewhat relieved when use is made of a coated electrode.

Quasi Arc Welding.—The electrodes used in quasi arc welding are made by the Quasi Arc Weldtrode Co., Brooklyn, N. Y., and are known as "weldtrodes." A mild-steel wire is used with a very small aluminum wire running lengthwise of it. Around the two is wrapped asbestos thread. This asbestos thread is held on by dipping the combination into something similar to waterglass. Either a.c. or d.c. may be used, at a pressure of about 105 volts, with a suitable resistance for regulating the current. The company's directions and claims for this process are: "The bared end of the weldtrode, held in a suitable holder, is connected to one pole of the current supply by means of a flexible cable, the return wire being connected to the work. In the case of welding small articles, the work is laid on an iron plate or bench to which the return wire is connected. Electrical contact is made by touching the work with the end of the weldtrode held vertically, thus allowing current to pass and an arc to form. The weldtrode, still kept in contact with the work, is then dropped to an angle, and a quasi-arc will be formed owing to the fact that the special covering passes into the igneous state, and as a secondary conductor maintains electrical connection between the work and the metallic core of the weldtrode. The action once started, the weldtrode melts at a uniform rate so long as it remains in contact, and leaves a seam of metal fused into the work. The covering material of the weldtrode, acting as a slag, floats and spreads over the surface of the weld as it is formed. The fused metal, being entirely covered by the slag, is protected from oxidation. The slag covering is readily chipped or brushed off when the weld cools, leaving a bright clean metallic surface. In welding do not draw the weldtrode along the seam, as it is burning away all the time, and therefore it is

only necessary to feed it down, but do this with a slightly lateral movement, so as to spread the heat and deposited metal equally to both sides of the joint. Care must be taken to keep feeding down at the same rate as the weldtrode is melting. On no account draw the weldtrode away from the work to make a continuous arc as this will result in putting down bad metal. The aim should be to keep the point of the weld-

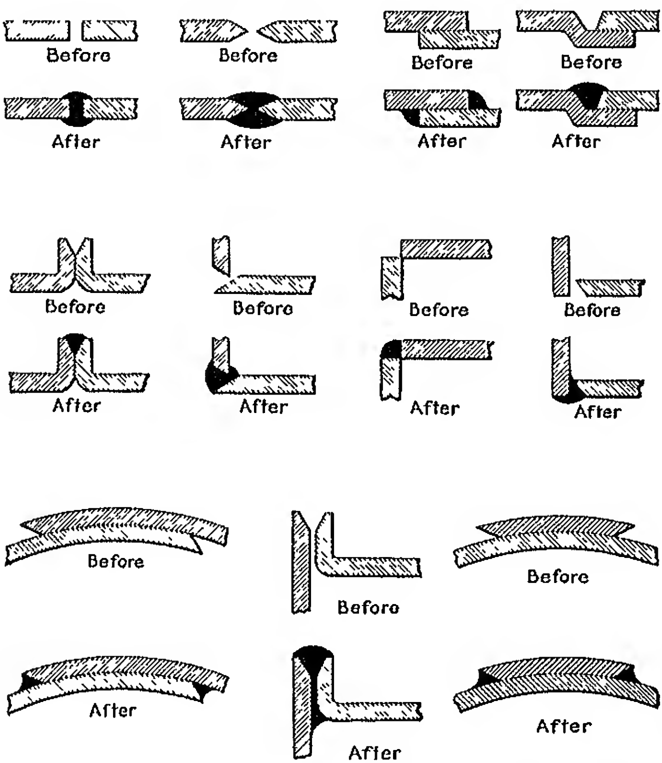


FIG. 64.—Typical Examples of Prepared and Finished Work.

trode just in the molten slag by the feel of the covering just rubbing on the work. By closely observing the operation, the molten metal can easily be distinguished from the molten slag, the metal being dull red and the slag very bright red."

The weldtrodes are supplied ready for use in standard lengths of 18 in., and of various diameters, according to the size and nature of the work for which they are required.

Typical Examples of Arc Welding.—The examples of welding shown in Figs. 64, 65 and 66 are taken from the manual issued by the Wilson Welder and Metals Co. They will be found very useful as a guide for all sorts of work. Fig. 64

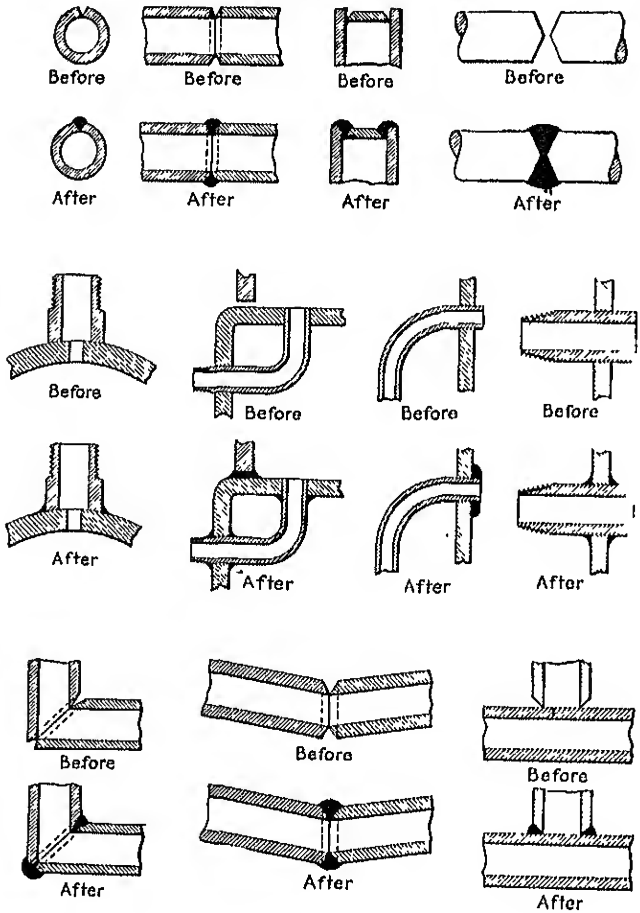


Fig. 65.—Examples of Tube Work.

shows miscellaneous plate or sheet jobs, Fig. 65 shows tube jobs, while Fig. 66 gives examples of locomotive-frame and boiler-tube welding.

As a basis for various welding calculations the following data will be found of use: On straight-away welding the

ordinary operator with helper will actually weld about 75 per cent of the time.

The *average* results of a vast amount of data show that an

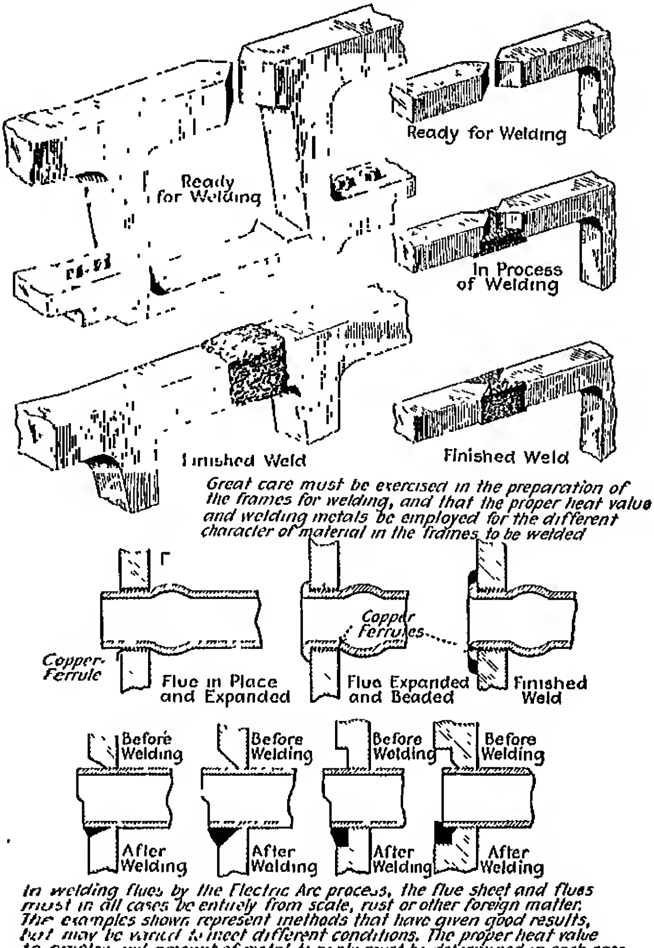


FIG. 66.—Examples of Electric Welding of Locomotive Frames and Boiler Tubes.

operator can deposit about 1.8 lb. of metal per hour. This rate depends largely upon whether the work is done out in the open or in a special place provided in the shop. For outside work such as on boats, an operator will not average

in general more than 1.2 lb. per hour, while in the shop the same operator could easily deposit the 1.8 lb. stated above. This loss in speed for outside work is brought about largely by the cooling action of the air and also somewhat by the added inconvenience to the operator. The value of pounds per hour given above is based on the assumption that the work has been lined up and is ready for welding. On the average 70 per cent of the weight of electrodes is deposited in the weld, 12 per cent is burned or vaporized and the remainder 18 per cent is wasted as short ends.

Other figures prepared by the Electric Welding Committee show the possible cost of a fillet weld on a ½-in. plate, using a motor generator set and bare electrodes to be as follows:

Average speed of welding on continuous straight away work	5 ft. per hour
Amount of metal deposited per running foot.............	.6 lb.
Current 150 amps, at 20 volts = 3 kilowatts.	
Motor generator eff. 50 per cent = 6 kw. ÷ 5 equals	1.2 k.w.h. per 1 ft. run
1.2 k.w.h. at 3 cents per k.w.h. equals.............	3.6 cents per ft.
Cost of electrode 10 cents per pound and allowing for waste ends, etc., equals.....................	7.2 cents per ft.
Labor at 65 cents per hour equals...............	13.00 cents per ft.
	23.8 cents per ft.

Suggestions for the Design of Welded Joints.—From an engineering point of view, every metallic joint whether it be riveted, bolted or welded, is designed to withstand a perfectly definite kind and amount of stress. An example of this is the longitudinal seam in the shell of a horizontal fire-tube riveted boiler. This joint is designed for tension and steam tightness only and will not stand even a small amount of transverse bending stress without failure by leaking. If a joint performs the function for which it was designed and no more, its designer has fulfilled his responsibilities and it is a good joint economically. Regardless of how the joint is made the design of joint which costs the least to make and which at the same time performs the functions required of it, with a reasonable factor of safety, is the best joint.

The limitations of the several kinds of mechanical and welded joints should be thoroughly understood.

A bolted joint is expensive, is difficult to make steam- or water-pressure tight, but has the distinguishing advantage that

it can be disassembled without destruction. Bolted joints which are as strong as the pieces bolted together are usually impracticable, owing to their bulk.

Riveted joints are less expensive to make than bolted joints but cannot be disassembled without destruction to the rivets. A riveted joint, subject to bending stress sufficient to produce appreciable deformation, will not remain steam- or water-pressure tight. Riveted joints can never be made as strong as the original sections because of the metal punched out to form the rivet holes.

There is no elasticity in either riveted, bolted or fusion-welded joints which must remain steam- or water-pressure tight. Excess material is required in the jointed sections of bolted or riveted joints, owing to the weakness of the joints.

Fusion-welded joints have as a limit of tensile strength the tensile strength of cast metal of a composition identical to that of the joined pieces. The limit of the allowable bending stress is also set by the properties of cast metal of the same composition as that of the joined pieces. The reason for this limitation is that on the margin of a fusion weld adjacent to the pieces joined, the metal of the pieces was heated and cooled without change of composition. Whatever properties the original metal had, due to heat or mechanical treatment, are removed by this action, which invariably occurs in a fusion weld. Regardless of what physical properties of the metal used to form the joint may be, the strength or ability to resist bending of the joint, as a whole, cannot exceed the corresponding properties of this metal in the margin of the weld. Thus, assuming that a fusion weld be made in boiler plate, having a tensile strength of 62,000 pounds. Assume that nickel-steel, having a tensile strength of 85,000 lb. be used to build up the joint. No advantage is gained by the excess 23,000 lb. tensile strength of the nickel-steel of the joint since the joint will fail at a point close to 62,000 lb. If appreciable bending stress be applied to the joint it will fail in the margin referred to.

The elastic limit of the built-in metal is the same as its ultimate strength for all practical purposes, but the ultimate strength is above the elastic limit of the joined sections in commercial structures.

In spite of the limitations of the fusion-welded joint it is

possible and practicable to build up a joint in commercial steel which will successfully resist any stress which will be encountered in commercial work.

The fundamental factor in the strength of a welded joint is the strength of the material added by the welding process. This factor depends upon the nature of the stress applied. The metal added by the welding process, when subject to tension, can be relied on in commercial practice to give a tensile strength of 45,000 lb. per square inch. This is an average condition; assuming that the metal added is mild steel and that the operation is properly done, the metal will have approximately the same strength in compression as in tension. When a torsional stress is applied to a welded joint the resultant stress is produced by a combination of bending, tension and compression, as well as shear. The resistance of the metal to shear may be figured at $^8/_{10}$ its resistance to tensile stress. The metal added by the welding process, with the present development in the art of welding, will stand very little bending stress. A fusion-welded joint made by the electric-arc process must be made stiffer than the adjacent sections in order that the bending stress shall not come in the joint. An electric weld, when properly made, will be steam- and water-pressure tight so long as bending of members of the structure does not produce failure of the welded joint.

Little is known at the present time in regard to the resistance of an electrically welded joint to dynamic stress, but there is reason to believe that the resistance to this kind of stress is low. However, owing to the fact that in most structures there is an opportunity for the members of the structure to flex and reduce the strain upon the weld, this inherent weakness of the welded joint does not interfere seriously with its usefulness.

A few tests have been made of high-frequency alternating stresses and it has been found that using the ordinary wire electrode the welded joint fails at a comparatively small number of alternations. This is of little importance in most structures since high-frequency alternating stress is not often encountered.

Stresses in Joints.—The accompanying cuts show a number of typical joints and the arrows indicate the stresses brought

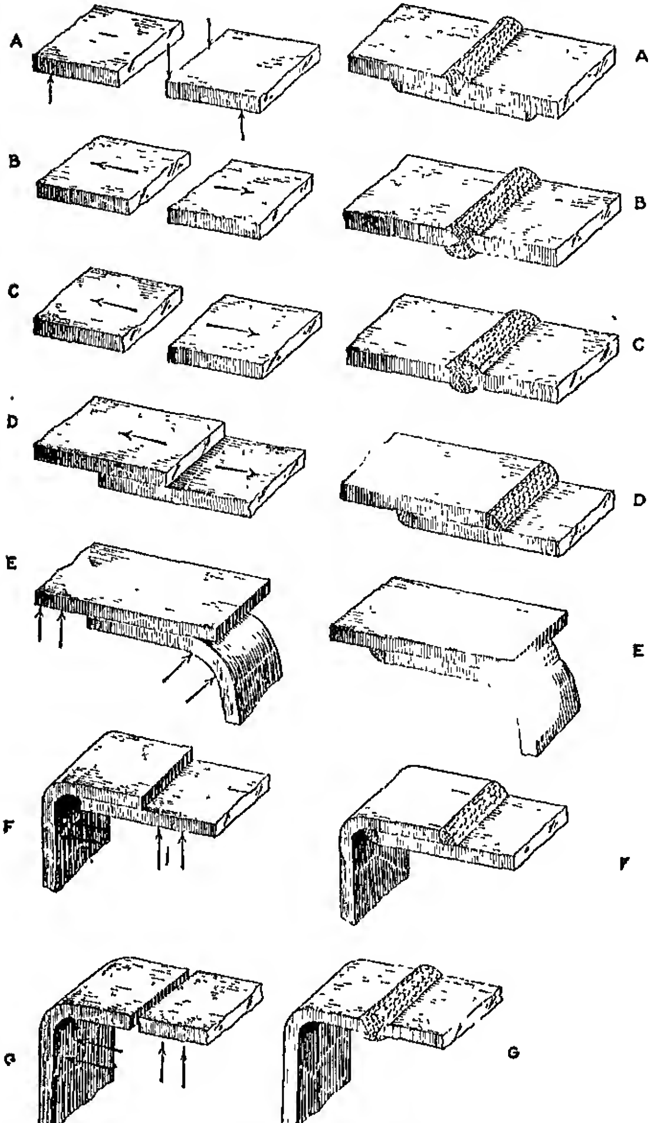


Fig. 67.—Joints Designed to Overcome Certain Stresses.

to bear on them. The proper way to weld each example is plainly shown.

In *A*, Fig. 67, it will be noted that a reinforcing plate is welded to the joint to make the joint sufficiently stiff to throw the bending outside the weld.

B shows a joint in straight tension. Since no transverse stress occurs the heavy reinforcing of *A* is not required. Just enough reinforcing is given the joint to make up for the deficiency in tensile strength of the metal of the weld.

C shows another method of building up a joint that is in

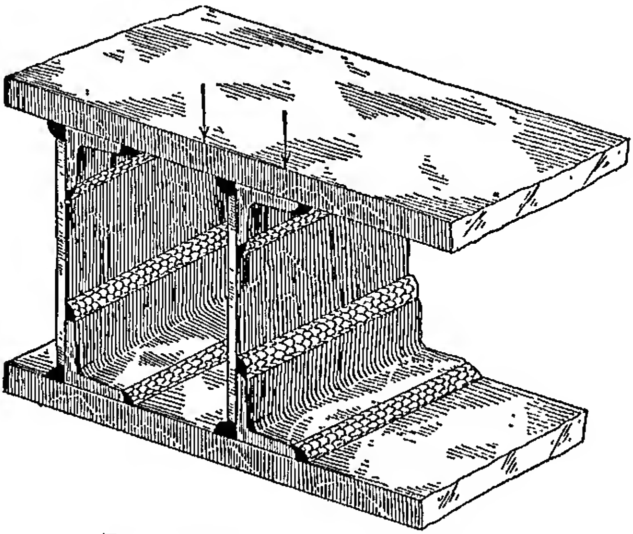


Fig. 68.—Plate and Angle Construction.

straight tension. It should be noted that in both *B* and *C* as much reinforcing is placed on one side of a center line through the plates as is placed on the other.

The original form of lap joint such as is used in riveting is shown at *D*. The method shown for welding this joint is the only method which can be used. It cannot be recommended because such a joint, when in straight tension, tends to bring the center line of the plate into coincidence with the center line of the stress. In so doing an excessive stress is placed on the welded material.

E shows the construction used in certain large tanks where

a flanged head is backed into a cylindrical shell. The principal stress to be resisted by the welded joint is that tending to push the head out of the shell. The welding process indicated in the figure will successfully do this. Owing to the friction between the weld and the shell, the outer weld would be sufficient to hold the weld in place for ordinary pressure. For higher pressures the inside weld should be made in addition.

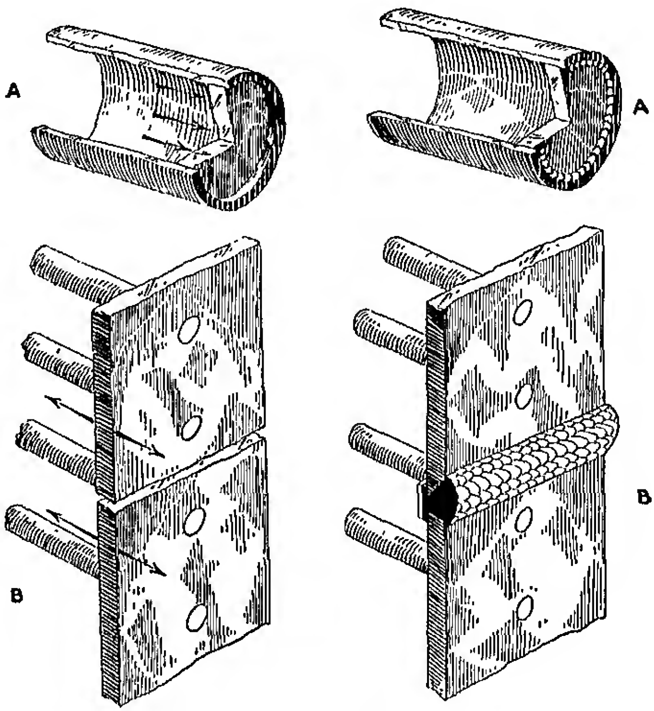


FIG. 69.—Pipe Heading and Firebox Sheet Work.

F and *G* show another method of welding a flanged head to the cylindrical shell. These methods are preferable to the method indicated in *E*. *G* represents the recommended practice.

Fig. 68 shows a plate and angle structure which might be used in ship construction. The particular feature to notice in the welding practice indicated, is that the vertical plates do not reach the entire distance between the horizontal plates.

This is merely a method of eliminating difficulties in welding the plates to the angle.

A in Fig. 69 shows a method of welding a head into a cylindrical pipe. The thickness of the head should be approximately twice the thickness of the wall of the pipe. The extra thickness plate is to gain sufficient stiffness in the head to make the stress on the welded material purely shear. The pressure from the inside tends to make the head assume a hemispherical shape. This would place a bending stress on the welded material if the head were thin enough to give at the proper pressure.

B shows a method of welding a crack in a fire-box sheet. The thin plate backing introduced at the weld makes the operation very much easier for the operator and produces the reinforcing of the water side of the fire-box sheet which is most desirable.

INSPECTION OF METALLIC ELECTRODE ARC WELDS

Determining the character of welded joints is of prime importance, says O. S. Escholz, and the lack of a satisfactory method, more than any other factor, has been responsible for the hesitancy among engineers of the extensive adoption of arc welding. To overcome this prejudice it is desirable to shape our rapidly accumulating knowledge of operation into an acceptable method of inspection.

Manufactured apparatus is practically all accepted on the basis of complying with a process specification rigidly enforced in conjunction with the successful reaction to certain tests applied to the finished product. Riveting impairs the strength of the joined plates, yet with a proper layout and intelligent inspection the completed structure possesses certain definite characteristics which do not require further verification. The inspector of a finished concrete structure is practically helpless, and the weakest sort of construction may be concealed by a sound surface. With careful supervision, however, the physical properties of the completed structure can be reliably gaged to the extent that the use of concrete is justified even in ship construction. With this in view, electric arc welding is susceptible to even better control than obtain in either of these structural operations.

The four factors which determine the physical characteristics of the metallic electrode arc welds are: Fusion, slag content, porosity and crystal structure.

Some of the other important methods that have been suggested and used for indicating these characteristics are:

1. Examination of the weld by visual means to determine (a) finish of the surface as an index to workmanship; (b) length of deposits, which indicates the frequency of breaking arc, and therefore the ability to control the arc; (c) uniformity of the deposits, as an indication of the faithfulness with which the filler metal is placed in position; (d) fusion of deposited metal to bottom of weld scarf as shown by appearance of under side of welded joint; (e) predominance of surface porosity and slag.

2. The edges of the deposited layers chipped with a cold chisel or calking tool to determine the relative adhesion of deposit.

3. Penetration tests to indicate the linked unfused zones, slag pockets and porosity by (a) X-ray penetration; (b) rate of gas penetration; (c) rate of liquid penetration.

4. Electrical tests (as a result of incomplete fusion, slag inclusions and porosity) showing variations in (a) electrical conductivity; (b) magnetic induction.

These tests if used to the best advantage would involve their application to each layer of deposited metal as well as to the finished weld. This, except in unusual instances, would not be required by commercial practice in which a prescribed welding process is carried out.

Of the above methods the visual examination is of more importance than generally admitted. Together with it the chipping and calking tests are particularly useful, the latter test serving to indicate gross neglect by the operator of the cardinal welding principles, due to the fact that only a very poor joint will respond to the tests.

The most reliable indication of the soundness of the weld is offered by the penetration tests. Obviously the presence of unfused oxide surfaces, slag deposits and blowholes will offer a varying degree of penetration. Excellent results in the testing of small samples are made possible by the use of the X-ray. However, due to the nature of the apparatus, the

amount of time required and the difficulty of manipulating and interpreting results, it can hardly be considered at the present time as a successful means to be used on large-scale production.

The rate that hydrogen or air leaks through a joint from pressure above atmospheric to atmospheric, or from atmospheric to partial vacuum, can readily be determined by equipment that would be quite cumbersome, and the slight advantage over liquid penetration in time reduction is not of sufficient importance to warrant consideration for most welds.

Of the various liquids that may be applied kerosene has marked advantages because of its availability, low volatility and high surface tension. Due to the latter characteristics kerosene sprayed on a weld surface is rapidly drawn into any capillaries produced by incomplete fusion between deposited metal and weld scarf, or between succeeding deposits, slag inclusions, gas pockets, etc., penetrating through the weld and showing the existence of an unsatisfactory structure by a stain on the emerging side. A bright-red stain can be produced by dissolving suitable oil-soluble dyes in the kerosene. By this means the presence of faults have been found that could not be detected with hydraulic pressure or other methods.

By the kerosene penetration a sequence of imperfect structure linked through the weld, which presents the greatest hazard in welded joints, could be immediately located, but it should be borne in mind that this method is not applicable to the detection of isolated slag or gas pockets nor small, disconnected unfused areas. It has been shown by various tests, however, that a weld may contain a considerable amount of distributed small imperfections, without affecting to a great extent its characteristics.

If a bad fault is betrayed by the kerosene test it is advisable to burn out the metal with a carbon arc before rewelding under proper supervision. By the means of sandblast, steam or gasoline large quantities of kerosene are preferably removed. No difficulty has been encountered on welding over a thin film of the liquid.

Electrical tests, by which the homogeneity of welds is determined, are still in the evolutionary stages, and many difficulties are yet to be overcome before this test becomes feasible.

Some of these difficulties are the elimination of the effect of contact differences, the influence of neighboring paths and fields, and the lack of practicable, portable instruments of sufficient sensibility for the detection of slight variations in conductivity or magnetic field intensity. No simple tests are plausible, excepting those which involve subjecting the metal to excessive stresses for determining the crystal structure. Control of this phase must be determined by the experience obtained from following a prescribed process.

The inspector of metallic arc electrode welds may consider that through the proper use of visual, chipping and penetrating tests a more definite appraisal of the finished joint may be obtained than by either riveting or concrete construction. The

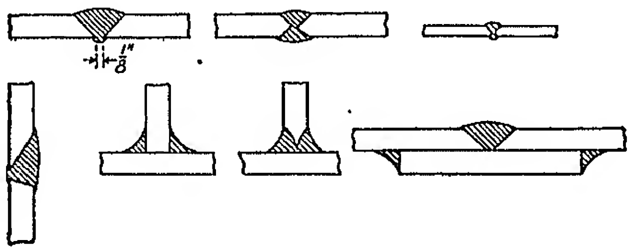


Fig. 70.—Typical Arc-weld Scarfs.

operation may be still further safeguarded by requiring rigid adherence to a specified process.

Good results are assured if correct procedure is followed.

Haphazard welding can no sooner produce an acceptable product than hit-or-miss weaving will make a marketable cloth. It is only logical that all the steps in a manufacturing operation should be regulated to obtain the best results. As it is most welders consider themselves pioneers in an unknown art that requires the exercise of a peculiar temperament for its successful evolution, and as a result welding operators enshroud themselves in the halo of an expert and do their work with a mystery bewildering to the untutored. Once in a while, due we might say to coincidences, these "experts" obtain a good weld, but more often the good weld may be attributed to the friction between slightly fused, plastered deposits.

In common with all other operations metallic electrode arc

square bar from a short arc is shown in Fig. 74, *A*, and in *B* is shown a porous, diffused deposit from a long arc. Top views of these welds are shown in Fig. 75. A short arc is

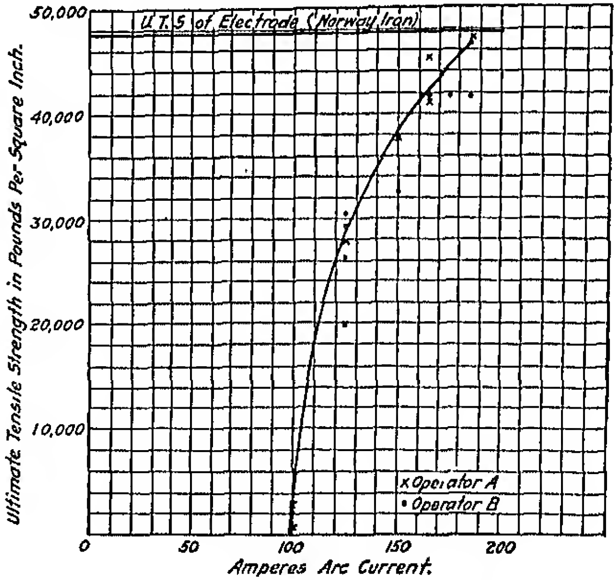


FIG. 73.—Variation in Weld Strength with Change in Arc Current.

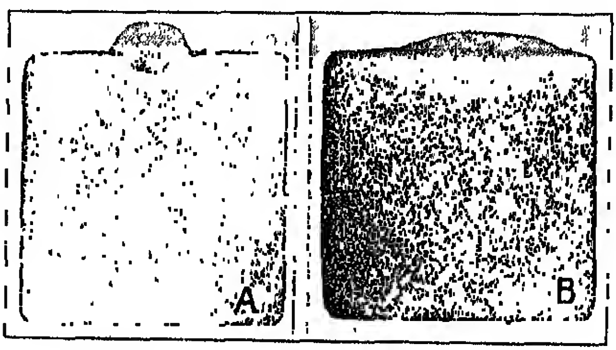


FIG. 74.—Sectional Views of Short and Long Arc Deposits.

usually maintained by a skillful operator, as the work is thereby expedited, less electrode material wasted and a better weld obtained because of improved fusion, decreased slag content

and porosity. On observing the arc current and arc voltage by meter deflection or from the trace of recording instruments, the inspector has a continuous record of the most important factors which affect weld strength, ductility, fusion, porosity, etc. The use of a fixed series resistance and an automatic time-lag reset switch across the arc to definitely fix both the arc current and the arc voltage places these important factors entirely beyond the control of the welder and under the direction of the more competent supervisor.

Heat Treatment and Inspection.—The method of placing the deposited layers plays an important part on the internal strains and distortion obtained on contraction. It is possible that part of these strains could be relieved by preheating and

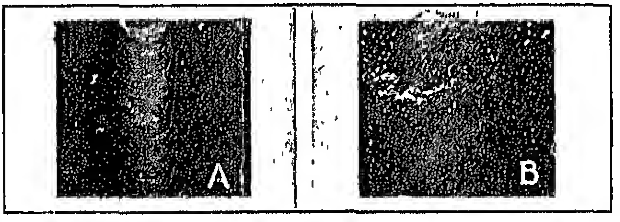


FIG. 75.—Top Views of Welds Shown in Fig. 74.

annealing as well as by the allowance made in preparation for the movement of the metal.

The heat treatment of a completed weld is not a necessity, particularly if it has been preheated for preparation and then subjected to partial annealing. A uniform annealing of the structure is desirable, even in the welding of the small sections of alloy and high-carbon steels, if it is to be machined or subjected to heavy vibratory stresses.

The inspector, in addition to applying the above tests to the completed joint and effectively supervising the process, can readily assure himself of the competency of any operator by the submission of sample welds to ductility and tensile tests or by simply observing the surface exposed on cutting through the fused zone, grinding its face and etching with a solution of 1 part concentrated nitric acid in 10 parts water.

It is confidently assumed, in view of the many resources at the disposal of the welding inspector, that this method of

obtaining joints will rapidly attain successful recognition as a dependable operation to be used in structural engineering.

EFFECTS OF THE CHEMICAL COMPOSITION OF METALLIC ARC WELDING ELECTRODES

In order to ascertain to what extent the chemical analysis of an electrode affected the welded material in metallic arc welding, says J. S. Orton, two electrodes *R* and *W* were chosen of widely different chemical analyses, each 0.148 in. in diameter. The *R* electrode was within the specifications of the Welding Research Committee except that the silicon content was a little high. The analyses were as follows:

	C	Mn	P	S	Si
R wire	0.17	0.57	0.007	0.028	0.14
W wire	0.39	1.01	0.005	0.024	0.12

The silicon content was rather high, but inasmuch as it was fairly constant in both electrodes the results are comparative.

A deposit was made on a ½-in. plate by means of a metallic arc, the welded section being approximately 1 ft. long, 6 in. wide and 1 in. thick. The welding machine used was of a well-known make, with a constant voltage of 37 volts at 130 amperes. The plates used for depositing the first layer were machined away and two test bars were made from each electrode, composed entirely of welded material. The ends were rough-machined and about 4½ in. in the middle of the specimens were finished carefully.

The physical characteristics of the plates are as shown in Table V.

TABLE V.—PHYSICAL CHARACTERISTICS OF PLATES

	Tensile Strength	Elastic Limit	Elongation	RA Brinnel
R-1.....................	57,300	43,400	8.0	15.3
2.....................	56,050	50,500	6.0	5.9
W-1.....................	76,200	64,000	7.5	13.0
2.....................	72,650	60,260	5.5	7.1

After these bars were pulled, chemical analyses were taken at various points to get the values given in Table VI.

TABLE VI.—CHEMICAL ANALYSES OF SPECIMENS

	C	Mn	P	S	Si
R-1	0.12	0.23	0.012	0.019	0.10
2	0.09	0.24	0.016	0.014	0.08
3	0.11	0.26	0.014	0.020	0.08
W-1	0.23	0.84	0.014	0.012	0.02
2	0.20	0.80	0.014	0.014	0.05
3	0.20	0.88	0.013	0.013	0.02

Photographs of the different fractures are shown in Fig. 77. *W-1,* which gave the highest tensile strength, shows 100 per cent. metallic structure with a silky appearance. *R-1* shows a coarse intergranular fracture. *R-2* shows a brittle, shiny crystalline fracture with a slag inclusion at the lower left-hand and upper right-hand corners of the bars. *W-2*

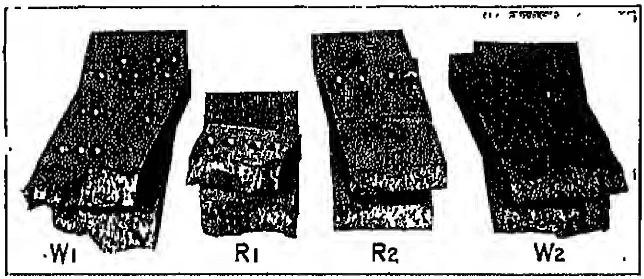


FIG. 76.—Fractures of Test Specimens.

shows partial crystalline and partial silky fracture. At the extreme right there is a portion which is not welded. This is probably the reason why *W-2* did not pull as much as the other. Undoubtedly, next to the chemical analysis, the quantity of slag in the weld has the biggest bearing on the tensile strength.

The structure of the test specimens is shown in the microphotographs of Fig. 77. In making these photographs, no attempt was made to make a complete microanalysis of the two different specimens, but rather it was intended to show the general difference in structure between the two different types of electrode. All of these photographs were taken at 150 diameters except the last two, which were taken at 100.

Photograph *R-1A* shows the general structure of the plate welded with the *R* electrode. This photograph shows a large-

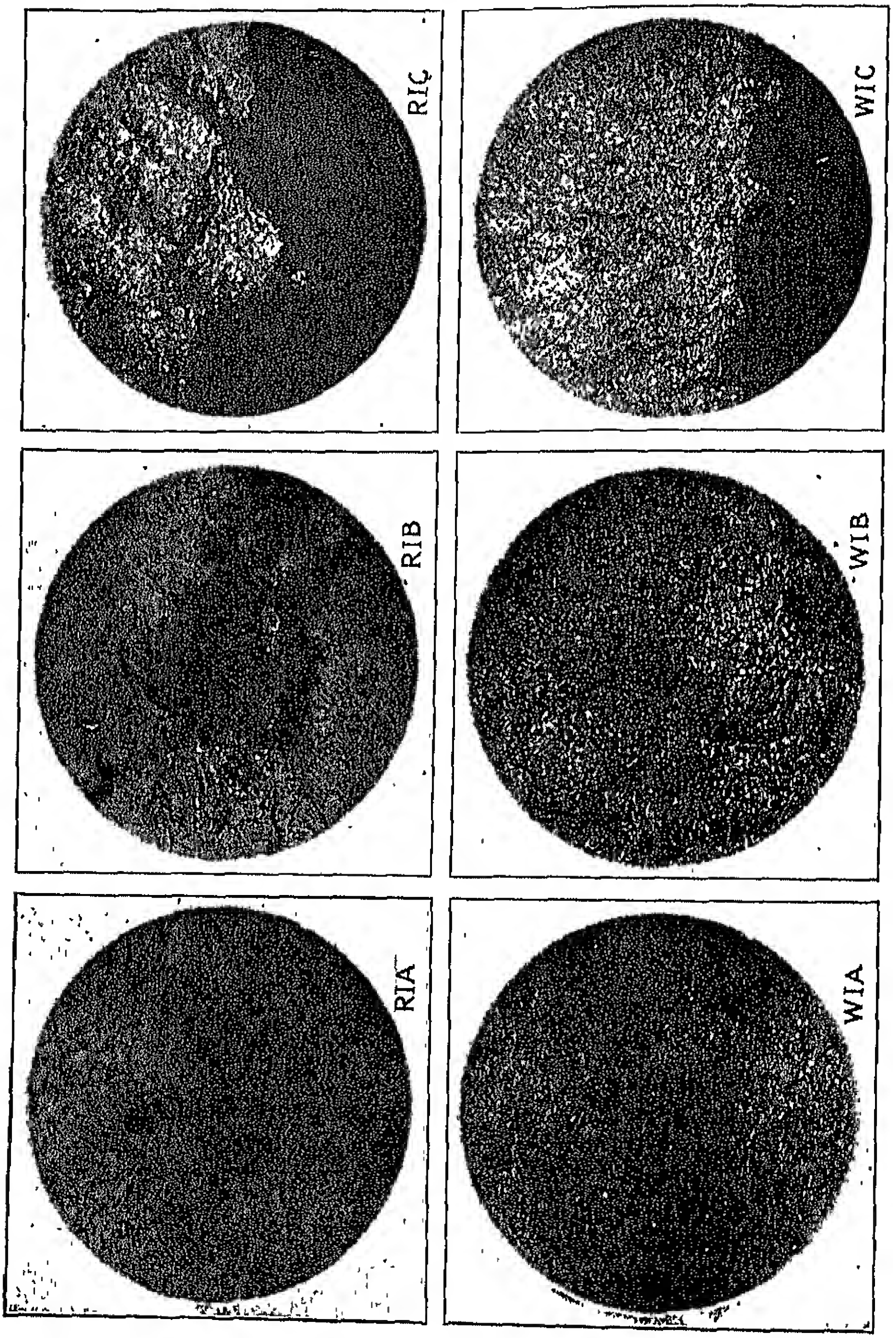


FIG. 77.—Microphotographs of Different Specimens.

grain growth and columnar structure which are characteristic of electric welds. Photograph *W1-A* shows the general structure of the plate welded with the *W* electrode. This shows comparatively small-grain structure. The structure seems to be much better than that of *R1-A*. Photograph *R1-B* shows a portion of a test specimen which was cut out of plate *R1* and bent to an angle of 10 deg. It is interesting to note here the opening up of the welded material adjacent to slag inclusions. Photograph *W1-B* shows a portion of a small specimen cut out from sample *W1* and bent to an angle of 10 deg., the same as in the case of *R1-B*. The welded material is opening up but not in the same degree nor around the slag inclusions as in the corresponding photograph *R1-B*. Photograph *R1-C* is a profile of the fracture of the *R1* sample after bending through an angle of 15 deg. Photograph *W1-C* shows the *W1* sample after being bent through an angle of 17 degrees.

It seems just as important to specify the chemical composition of the electrode used in metallic arc welding as it is to specify the chemical composition in ordering any other type of steel.

Chemical composition seems to affect the physical properties in electrodes as well as other steel.

An excess of manganese seems to be needed in electrodes.

The relation between the carbon and manganese of an electrode should be approximately one to three.

High-carbon manganese wire tends not only to improve the weld on account of the amount of carbon and manganese in the welded material, but also on account of the type of structure which this wire lends to the deposited metal.

There is a smaller amount of oxide and slag inclusions with a high-carbon manganese wire than with a comparatively low-carbon manganese wire.

WELDING COMMITTEE ELECTRODES

After an exhaustive series of tests the Welding Committee drew up the following tentative specification for electrodes intended to be used in welding mild steel of shipbuilding quality:

Chemical Composition.—Carbon, not over 0.18 per cent; manganese, not over 0.55 per cent; phosphorus, not over 0.05

per cent; sulphur, not over 0.05 per cent; silicon, not over 0.08 per cent.

Sizes:	Fraction of Inch	Lbs. Per Foot	Foot Per Lb.	Lbs. Per 100 Ft.
	1/8	0.0416	24	4.16
	5/32	0.0651	15.35	6.51
	3/16	0.0937	10.66	9.37

Allowable tolerance 0.006 plus or minus.

Material.—The material from which the wire is manufactured shall be made by any approved process. Material made by puddling process not allowed.

Physical Properties.—Wire to be of uniform homogeneous structure, free from segregation, oxides, pipes, seams, etc., as proven by micro-photographs. This wire may or may not be covered.

Workmanship and Finish.—(*a*) Electric welding wire shall be of the quality and finish known as "Bright Hard" or "Soft Finish." "Black Annealed" or "Bright Annealed" wire shall not be supplied. (*b*) The surface shall be free from oil or grease.

Tests.—The commercial weldability of these electrodes shall be determined by means of tests by an experienced operator, who shall demonstrate that the wire flows smoothly and evenly through the arc without any detrimental phenomena.

CHAPTER VII

ARC WELDING TERMS AND SYMBOLS

In order to aid the standardization of the various types of joints and welding operations the practice recommended by the Welding Committee of the Emergency Fleet Corp., for

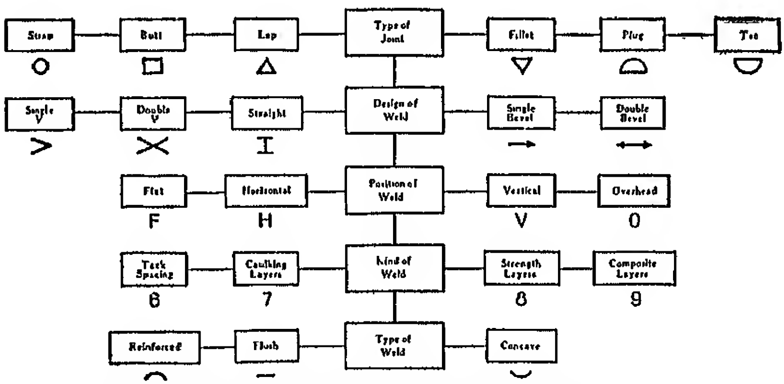


FIG. 78.—Standard Symbols Recommended by the Welding Committee of the Emergency Fleet Corporation.

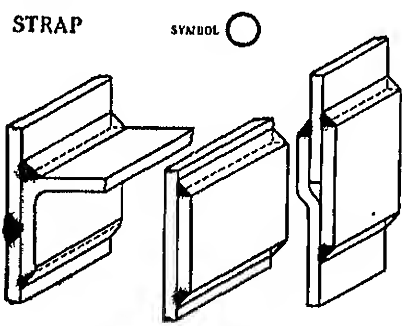


FIG. 79.

ship work, is given. The symbol chart is shown in Fig. 78 and the application of special terms and symbols is individually shown in Figs. 79 to 112 inclusive.

Fig. 79.—**A Strap weld** is one in which the seam of two adjoining plates or surfaces is reinforced by any form or shape to add strength and stability to the joint or plate. In this form of weld the seam can only be welded from the side of the work opposite the reinforcement, and the reinforcement, of whatever

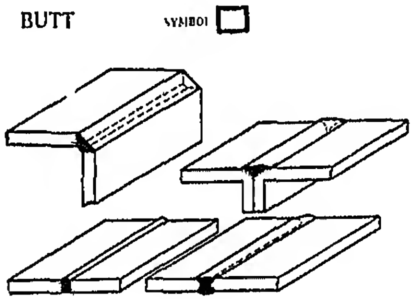


Fig. 80.

shape, must be welded from the side of the work to which the reinforcement is applied.

Fig. 80.—**A Butt weld** is one in which two plates or surfaces are brought together edge to edge and welded along the seam thus formed. The two plates when so welded form a perfectly

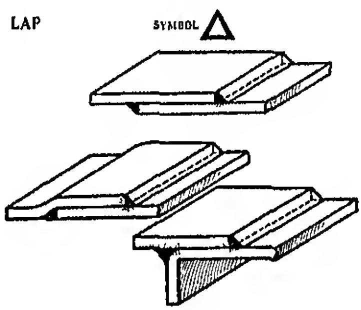


Fig. 81.

flat plane in themselves, excluding the possible projection caused by other individual objects as frames, straps, stiffeners, etc., or the building up of the weld proper.

Fig. 81.—**A Lap weld** is one in which the edges of two planes are set one above the other and the welding material so applied as to bind the edge of one plate to the face of the

other plate. In this form of weld the seam or lap forms a raised surface along its entire extent.

Fig. 82.—**A Fillet weld** is one in which some fixture or member is welded to the face of the plate, by welding along

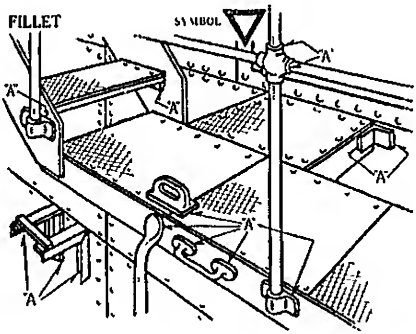


Fig. 82.

the vertical edge of the fixture or member (see welds shown and marked A). The welding material is applied in the corner thus formed and finished at an angle of forty-five degrees to the plate.

Fig. 83.—**A Plug weld** is one used to connect the metals by

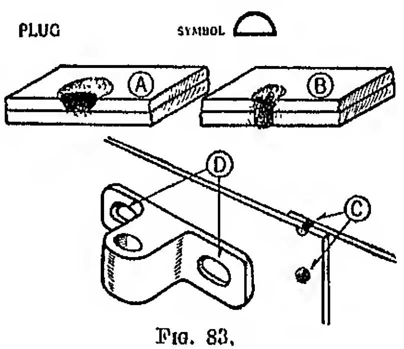


Fig. 83.

welding through a hole in either one plate A or both plates B. Also used for filling through a bolt hole as at C, or for added strength when fastening fixtures to the face of a plate by drilling a countersunk hole through the fixtures and applying the welding material through this hole, as at D, thereby fastening the fixture to the plate at this point.

FIG. 84.—**A Tee weld** is one where one plate is welded vertically to another as in the case of the edge of a transverse bulkhead A, being welded against the shellplating or deck. This is a weld which in all cases requires *exceptional* care and can only be used where it is possible to work from both sides

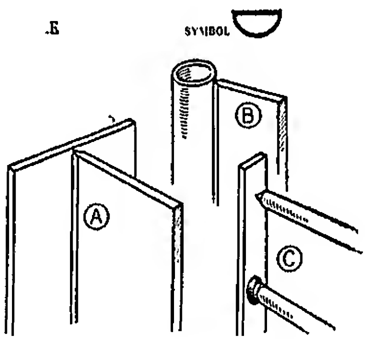


FIG. 84.

of the vertical plate. Also used for welding a rod in a vertical position to a flat surface, as the rung of a ladder C, or a plate welded vertically to a pipe stanchion B, as in the case of water closet stalls.

FIG. 85.—**A Single "V"** is applied to the "edge finish" of a plate when this edge is beveled from *both* sides to an

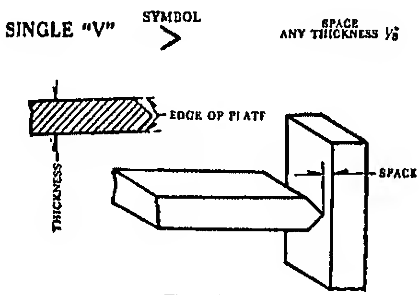


FIG. 85.

angle, the degrees of which are left to the designer. To be used when the "V" side of the plate is to be a maximum "strength" weld, with the plate setting vertically to the face of adjoining member, and only when the electrode can be applied from both sides of the work.

FIG. 86.—Double "V" is applied to the "edge finish" of two adjoining plates when the adjoining edges of both plates

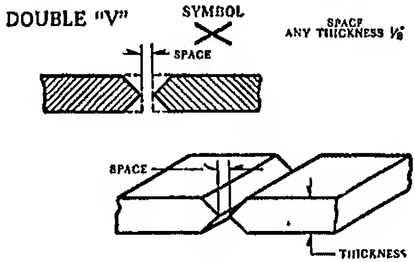


FIG. 86.

beveled from *both* sides to an angle, the degrees of which are left to the designer. To be used when the two plates are to be "butted" together along these two sides for a maximum

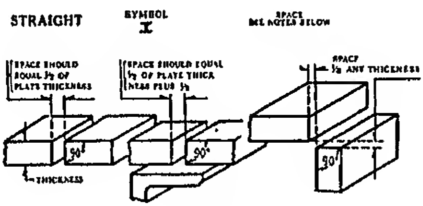


FIG. 87.

"strength" weld. Only to be used when welding can be performed from both sides of the plate.

FIG. 87.—**Straight** is applied to the "edge finish" of a plate, when this edge is left in its crude or sheared state. To be

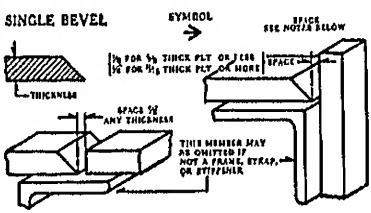


FIG. 88.

used only where maximum strength is *not* essential, or unless used in connection with strap, stiffener or frame, or where it is impossible to otherwise finish the edge. Also to be used

for a "strength" weld, when edges of two plates set vertically to each other—as the edge of a box.

Fig. 88.—**Single Bevel** is applied to the edge finish of a

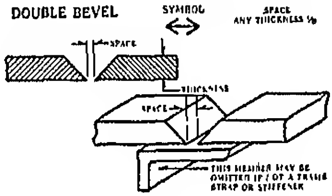


Fig. 89.

plate, when this edge is beveled from *one* side only to an angle, the degrees of which are left to the designer. To be used for "strength" welding, when the electrode can be applied

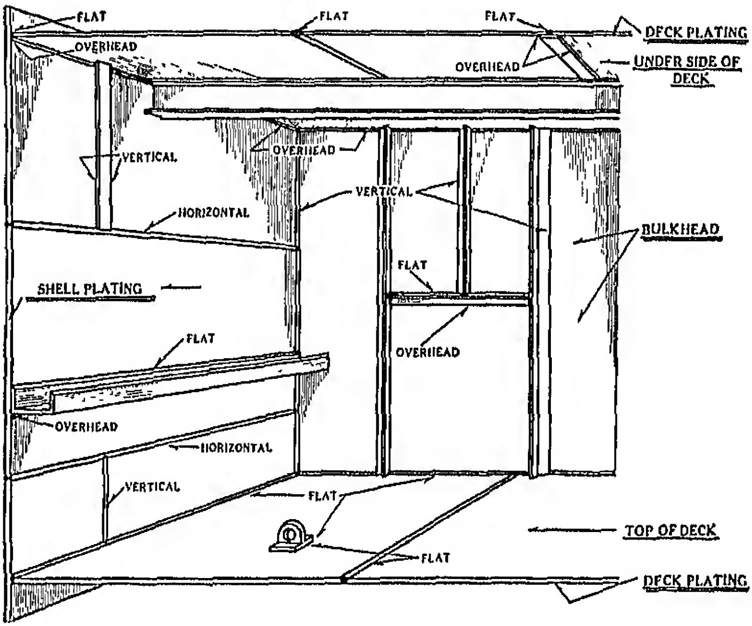


Fig. 90.

from *one* side of the plate only, or where it is impossible to finish the adjoining surface.

Fig. 89.—**Double Bevel** is applied to the edge finish of two adjoining plates, when the adjoining edges of both plates are

eveled from *one* side only to an angle, the degrees of which re left to the designer. To be used where maximum strength s required, and where electrode can be applied from *one* side f the work only.

FIG. 90.—**Flat position** is determined when the welding naterial is applied to a surface on the same plane as the deck, llowing the electrode to be held in an upright or vertical osition. The welding surface may be entirely on a plane vith the deck, or one side may be vertical to the deck and velded to an adjoining member that is on a plane with the leck.

Horizontal position is determined when the welding material s applied to a seam or opening, the plane of which is vertical o the deck and the line of weld is parallel with the deck,

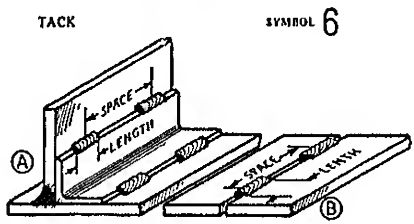


FIG. 91.

llowing the electrode to be held in an inboard or outboard osition.

Vertical position is determined when the welding material s applied to a surface or seam, whose line extends in a direcion from one deck to the deck above, regardless of whether he adjoining members are on a single plane or at an angle o each other. In this position of weld, the electrode would lso be held in a partially horizontal position to the work.

Overhead position is determined when the welding material s applied from the under side of any member whose plane s parallel to the deck and necessitates the electrode being held in a downright or inverted position.

FIG. 91.—**A Tack weld** is applying the welding in small ections to hold two edges together, and should always be specified by giving the *space* from center to center to weld nd the *length* of the weld itself. No particular "design of weld" is necessary of consideration.

A Tack is also used for temporarily holding material in place that is to be solidly welded, until the proper alinement and position is obtained, and in this case neither the *length, space, nor design of weld* are to be, specified.

Fig. 92.—**A Caulking weld** is one in which the density of

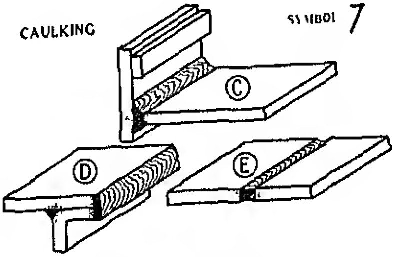


Fig. 92.

the crystalline metal, used to close up the seam or opening, is such that no possible leakage is visible under a water, oil or air pressure of 25 lbs. per square inch. The ultimate strength of a caulking weld is not of material importance—neither is the "design of weld" of this kind necessary of consideration.

Fig. 93.—**A Strength weld** is one in which the sectional

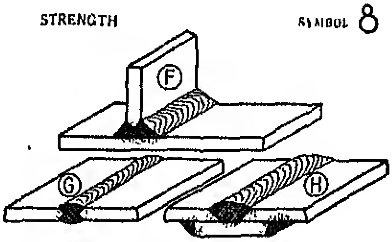


Fig. 93.

area of the welding material must be so considered that its tensile strength and elongation per square inch must equal at least 80 per cent of the ultimate strength per square inch of the surrounding material. (To be determined and specified by the designer.) The welding material can be applied in any number of layers beyond a minimum specified by the designer.

The density of the crystalline metals is *not* of vital im-

portance. In this form of weld, the "design of weld" must be specified by the designer and followed by the operator.

Fig. 94.—**A Composite weld** is one in which both the strength and density are of the most vital importance. The *strength* must be at least as specified for a "strength weld," and the density must meet the requirements of a "caulking weld"

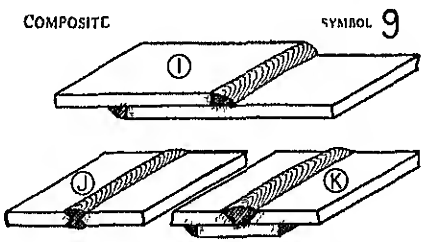


Fig. 94.

both as above defined. The minimum number of layers of welding material must always be specified by the designer, but the welder must be in a position to know if this number must be increased according to the welder's working conditions.

Fig. 95.—**Reinforced** is a term applied to a weld when the top layer of the welding material is built up above the plane

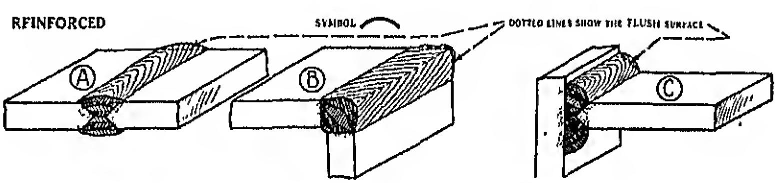


Fig. 95.

of the surrounding material as at A or B, or when used for a corner as at C. The top of final layer should project above a plane of 45 degrees to the adjoining material. This 45 degree line is shown "dotted" in C. This type is chiefly used in a "strength" or "composite" kind of weld for the purpose of obtaining the maximum strength efficiency, and should be specified by the designer, together with a minimum of layers of welding material.

Fig. 96.—**Flush** is a term applied to a weld when the top layer is finished perfectly flat or on the same plane as on the adjoining material as shown at D and E or at an angle of 45 degrees when used to connect two surfaces at an angle to each other as at F. This type of weld is to be used where a maximum tensile strength is not all important and must be

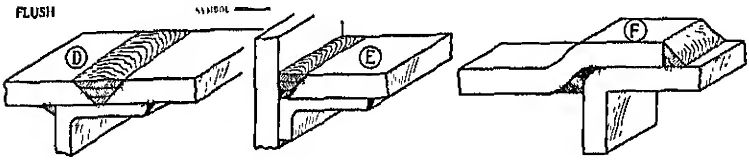


Fig. 96.

specified by the designer, together with a minimum number of layers of welding material.

Fig. 97.—**Concave** is a term applied to a weld when the top layer finishes below the plane of the surrounding material as at G, or beneath a plane of 45 degrees at an angular connection as at H and J.

To be used as a weld of no further importance than filling

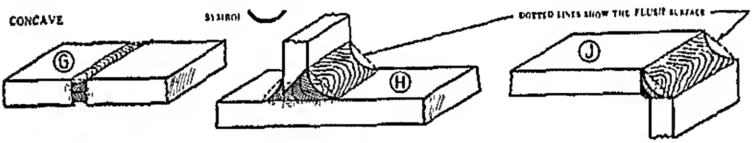


Fig. 97.

in a seam or opening, or for strictly caulking purposes, when it is found that a minimum amount of welding material will suffice to sustain a specified pound square inch pressure without leakage. In this "type of weld" it will not be necessary for the designer ordinarily to specify the number of layers of material owing to the lack of structural importance.

COMBINATION SYMBOLS

Fig. 98 shows a strap holding two plates together, setting vertically, with the welding material applied in not less than three layers at each edge of the strap, as well as between the plates with a reinforced, composite finish, so as to make the welded seams absolutely water, air or oil tight, and to

attain the maximum tensile strength. The edges of the strap and the plates are left in a natural or sheared finish. This type of welding is used for particular work where maximum strains are to be sustained.

Fig. 99 shows a strap holding two plates together hori-

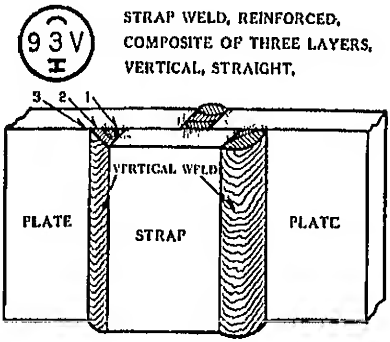


Fig. 98.

zontally, welded as a strength member with a minimum of three layers and a flush finish. Inasmuch as the strap necessitates welding of the plates from one side only, both edges of the plates are bevelled to an angle, the degrees of which are left to the discretion of the designer. The edges of the

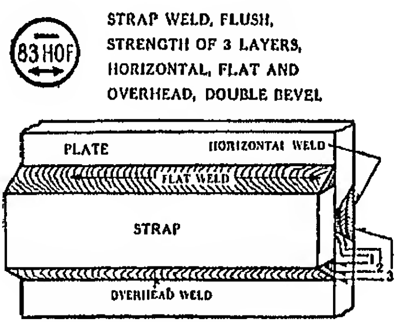


Fig. 99.

strap are left in a natural or sheared state, and the maximum strength is attained by the mode of applying the welding material, and through the sectional area per square inch exceeding the sectional area of the surrounding material.

Fig. 100 represents two plates butted together and welded

flat, with a composite weld of not less than three layers, and a reinforced finish. A strap is attached by means of overhead tacking, the tacks being four inches long and spaced eight inches from center to center. In this case, the welding of the plates of maximum strength and water, air or oil tight,

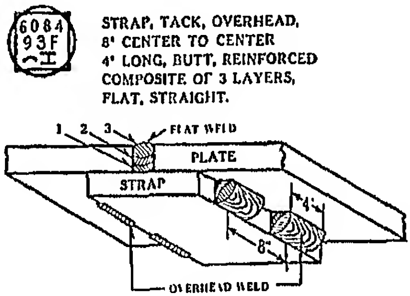


FIG. 100.

but the tacking is either for the purpose of holding the strap in place until it may be continuously welded, or because strength is not essential. All the edges are left in their natural or sheared state.

FIG. 101 represents a butt weld between two plates with the welding material finished concaved and applied in a minimum of two layers to take the place of caulking. The edges of the plates are left in a natural shear cut finish. This symbol will be quite frequently used for deck plating or any other place where strength is not essential, but where the material must be water, air or oil tight.

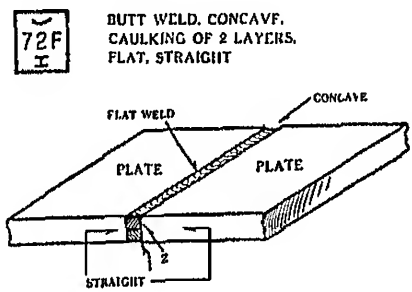


FIG. 101.

FIG. 102 is used where the edges of two plates are vertically

butted together and welded as a strength member. The edges of adjoining plates are finished with a "double vee" and the minimum of three layers of welding material applied from each side, finished with a convex surface, thereby making the sectional area per square inch of the weld greater than that

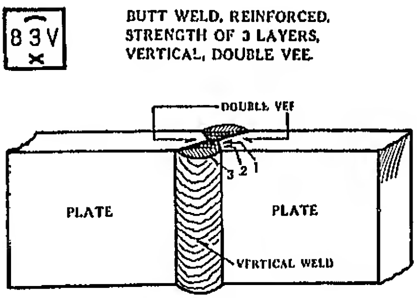


Fig. 102.

of the plates. This is a conventional symbol for shell plating or any other members requiring a maximum tensile strength, where the welding can be done from both sides of the work.

Fig. 103 shows two plates butted together in a flat position where the welding can only be applied from the top surface. It shows a weld required for plating where both strength and

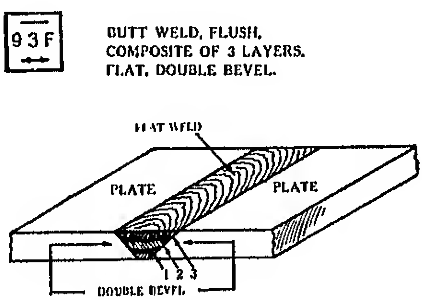


Fig. 103.

watertightness are to be considered. The welding material is applied in a minimum of three layers and finished flush with the level of the plates. Both edges of the adjoining plates are beveled to an angle, the degrees of which are left to the discretion and judgment of the designer, and should only be used when it is impossible to weld from both sides of the work.

Fig. 104 shows the edges of two plates lapping each other with the welding material applied in not less than two layers at each edge, with a concaved caulking finish, so applied, as to make the welded seams absolutely water, air or oil tight.

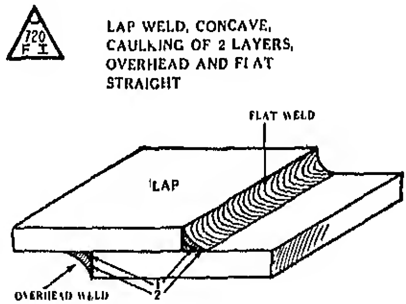


Fig. 104.

The edges of the plates themselves are left in a natural or shared finish. Conditions of this kind will often occur around bulkhead door frames where maximum strength is not absolutely essential.

Fig. 105 is somewhat exaggerated as regards the bending

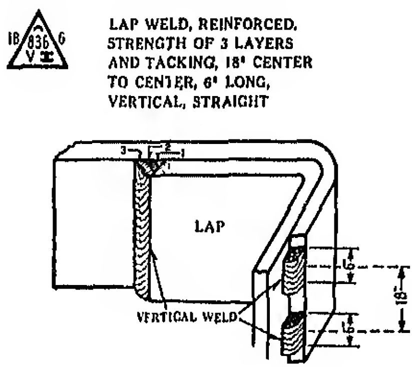


Fig. 105.

of the plates, but it is only shown this way to fully illustrate the tack and continuous weld. It shows the edges of the plates lapped with one edge welded with a continuous weld of a minimum of three layers with a reinforced finish thereby giving a maximum tensile strength to the weld, and the other

edge of the plate, tack welded. The tacks are six inches long with a space of 12 inches between the welds or 18 inches from center to center of welds. In both cases, the edges of the plates are left in a natural or sheared state.

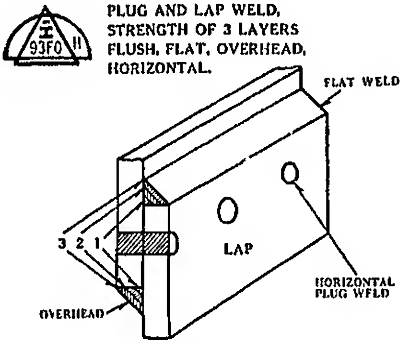


FIG. 106.

FIG. 106 shows a condition exaggerated, which is apt to occur in side plating where the plates were held in position with bolts for the purpose of alinement before being welded. The edges are to be welded with a minimum of three layers of welding material for a strength weld and finished flush,

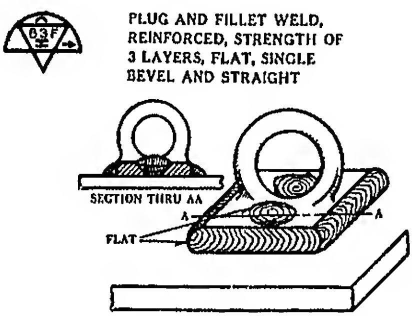


FIG. 107.

and after the bolts are removed, the holes thus left are to be filled in with welding material in a manner prescribed for strength welding. The edges of the plates are to be left in a natural or sheared state, which is customary in most cases of lapped welding.

FIG. 107 shows a pad eye attached to a plate by means of a fillet weld along the edge of the fixture, and further strengthened by plug welds in two countersunk holes drilled in the fixture. The welding material is applied in a flat position for a strength weld with a minimum of three layers

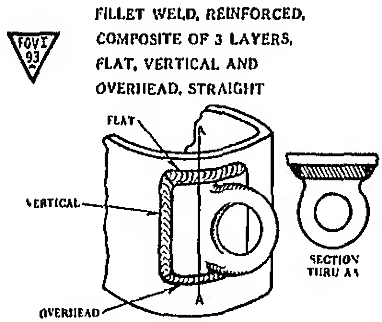


FIG. 108.

and a reinforced finish. The edges of the holes are beveled to an angle, which is left to the judgment of the designer, but the edges of the fixture are left in their natural state. This method is used in fastening fixtures, clips or accessories that would be subjected to an excessive strain or vibration

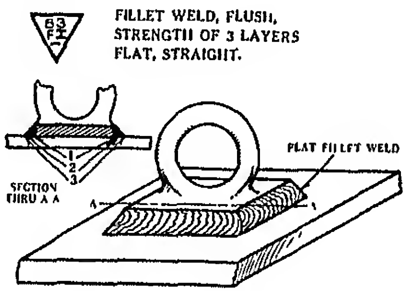


FIG. 109.

FIG. 108 shows a fixture attached to a plate by means of a composite weld of not less than three layers with a reinforced finish. The fixture being placed vertically, necessitates a combination of flat, vertical and overhead welding in the course of its erection. Although a fixture of this kind would never

be required to be watertight, the composite symbol is given simply as a possibility of a combination.

Fig. 109 represents a fixture attached to a plate by a strength fillet weld of not less than three layers, finished flush.

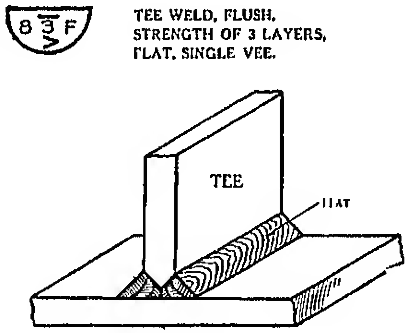


Fig. 110.

The edges of the fixture are left in their natural state, and the welding material applied in the corner formed by the vertical edge of the fixture in contact with the face of the plate.

Fig. 110 illustrates the edge of a plate welded to the face of another plate, as in the case of the bottom of a transverse

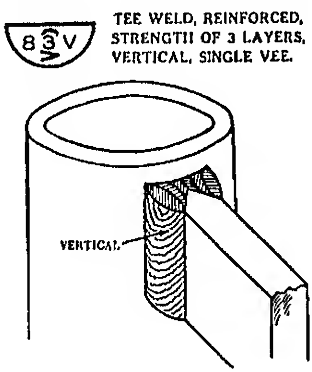


Fig. 111.

bulkhead being welded against the deck plating. To obtain a maximum tensile strength at the joint, the edge of the plate is cut to "single vee" and welded on both sides with a strength weld of not less than three layers, and finished flush. This would be a convenient way of fastening the intercostals to

the keelsons. In this particular case, the welding is done in a flat position.

Fig. 111 shows another case of tee weld with the seam setting in a vertical position, and the welding material applied from both sides of the work. The edge of the plate is finished with a "single vee" and a minimum of three layers of welding material applied from each side, finished with a convex surface, thereby making the sectional area, per square inch of the weld, greater than that of the plate, allowing for a maximum tensile strength in the weld.

Fig. 112 represents an example of the possible combination

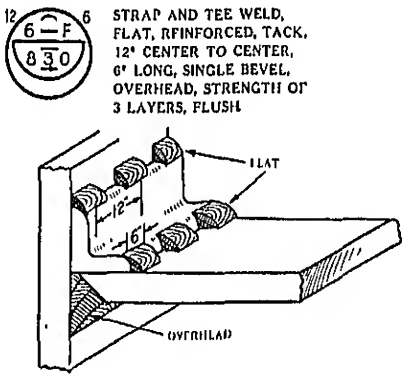


Fig. 112.

of symbols. An angle iron is tack welded to the plate in the form of a strap or stiffener, though in actual practice, this might never occur. The tacks are spaced twelve inches from center to center, and are six inches long, and applied in a flat position, with a reinforced finish. As the strap prevents welding the plate from both sides, the edge of the plate is beveled, and the welding material applied for strength in not less than three layers in an overhead position and finished flush. Note that in specifying tack welds, it is essential to give the space from center to center of weld, and length of weld by use of figures representing inches placed either side of the circumscribing symbol of the combination.

CHAPTER VIII

EXAMPLES OF ARC-WELDING JOBS

Probably no mechanical job ever attracted more general attention than the repair of the German ships seized by us when we entered the World War. Even the mechanically minded Germans repeatedly declared that repairing was an impossibility, but the American engineers and mechanics showed the Hun that he had, as usual, vastly over-rated his own knowledge. One big factor in making the Hun so positive in this case, was his utter ignorance regarding the possibilities of arc welding—but he learned and in the teaching many others were also enlightened.

The work necessary on these German ships, of course, included much besides welding of the broken castings, but the welding work was of primary importance.

The principal ships on which this welding work was done were the:

U. S. Name	German name	I.H.P.	Gross Tonnage	Class of Vessel
Aeolus	Grosser Kurfurst	8,400	13,102	Transport
Agamemnon	Kaiser Wilhelm II	45,000	19,361	Transport
America	America	15,800	22,621	Transport
Antigne	Neckar	5,500	9,835	Transport
Covington	Cincinnati	10,900	16,339	Transport
George Washington	George Washington	21,000	25,570	Transport
Huron	Friedrich der Grosse	6,800	10,771	Transport
Leviathan	Vaterland	90,000	54,282	Transport
Madawaska	Koenig Wilhelm II	7,400	9,410	Transport
Martha Washington	Martha Washington	6,940	8,312	Transport
Mercury	Barbarossa	7,200	10,984	Transport
Mt. Vernon	Kronprinzessin Cecelie	45,000	19,503	Transport
Pocahontas	Prinzess Irene	9,000	10,983	Transport
Powhatan	Hamburg	9,000	10,893	Transport
President Grant	President Grant	8,500	18,072	Transport
President Lincoln	President Lincoln	8,500	18,168	Transport
Savannah	Saxonia	2,500	4.424	Repair Shop
Susquehanna	Rhein	9,520	10.058	Transport
Philippines	Bulgaria	4,200	10,924	Shipping Bd.

The total gross tonnage of the ships named was 288,780 tons, and the welding work was done by the Wilson Welder and Metals Co. of New York, using their "plastic-arc" process.

Seventy Cylinders Saved Without Replacement.—In all, there were thirty-one ships interned in the port of New York. Of these thirty-one ships, twenty-seven were German and four Austrian. Of the German ships, two were sailing vessels and four were small steamers which the Germans had not taken pains to damage materially. This left twenty-one German ships whose engines and auxiliaries were damaged seriously, ranging in size from the "Vaterland," the pride of the Hamburg-American Line, of 54,000 tons, to the "Nassovia," of 3,900 tons.

On the cylinders of the twenty vessels of German origin, not counting for the moment the turbine-driven "Vaterland," there were no less than 118 major breaks which would have entailed the renewal of some seventy cylinders if ordinary practice had been followed. In fact, such was the recommendation of the surveying engineers in their original report.

To any engineer familiar with the conditions at that time in the machine shops and foundries in the vicinity of New York, also in the drafting rooms, the problem of producing seventy cylinders of the sizes required by these vessels would seem almost impossible, and it is pretty well established that some vessels would have had to wait nearly two years for this equipment.

It must be remembered that few drawings of these engines were available, and those in many cases were not discovered until months after the repairs had started. Therefore, it would have been necessary to make drawings from the actual cylinders, and competent marine engine draftsman not already flooded with work did not exist.

The cylinders of fifteen vessels were successfully welded, while those of six were repaired by fitting mechanical patches, or, in other words, eighty-two of the major breaks were repaired by welding and thirty-six by mechanical patches.

It was not until July 12 that the final decision was made placing the transport service in the hands of the Navy and designating what ships were to be transferred from the control of the Shipping Board to that of the Navy Department. How-

ever, the first two large ships, the "Friedrich der Grosse," now the "Huron," and the "Prinzess Irene," now the "Pocahontas," were ready for sea on Aug. 20, in spite of the fact that the engines on these vessels were among the worst damaged of them all, the "Irene" having the whole side of the first intermediate valve chest broken out on each engine, the side of the high-pressure cylinder on each engine destroyed, and other smaller breaks, which, under ordinary methods, would have necessitated the renewal of four cylinders. The "Friedrich der Grosse" had the following breaks: Broken valve chest of high-pressure cylinder of each engine (valve chest cast in one with the cylinder), flanges knocked off both valve chest and cylinder covers, steam inlet nozzles knocked off both first intermediate valve chests and walls between the two valves in each check broken out, also steam inlet nozzles on both second intermediate valve chests broken off.

These two vessels were the first in which straight electric welding was used, that is, where patches were not bolted to the cylinder walls.

Method of Repair.—The nature of some of the breaks in castings is shown by the accompanying photographs, which were taken at various stages of the work.

A, Fig. 113, shows the break in the starboard high-pressure cylinder of the North German Lloyd steamer "George Washington." This break was effected by drilling a row of holes about an inch apart and knocking the piece out with a ram.

To prepare this for welding it was necessary to chisel off the surface only roughly, build a pattern of the break, cast a steel piece from the pattern, stud up the surface of the cast iron of the cylinder with a staggered row of steel studs ⅝ in. in diameter, projecting ½ in. from the cylinder, bevel the edge of the cast piece, place the piece in position as shown in *B*, and make the weld. When completed, the appearance of the work is as it appears in *C*. The broad belt of welded metal is due to the laying of a pad of metal over the rows of studs previously noted.

It cannot be too strongly insisted that tests have shown conclusively that the weld can be properly made without this pad; that is, if the approximate strength of the original metal is all that is desired—in which case the studding of the metal is

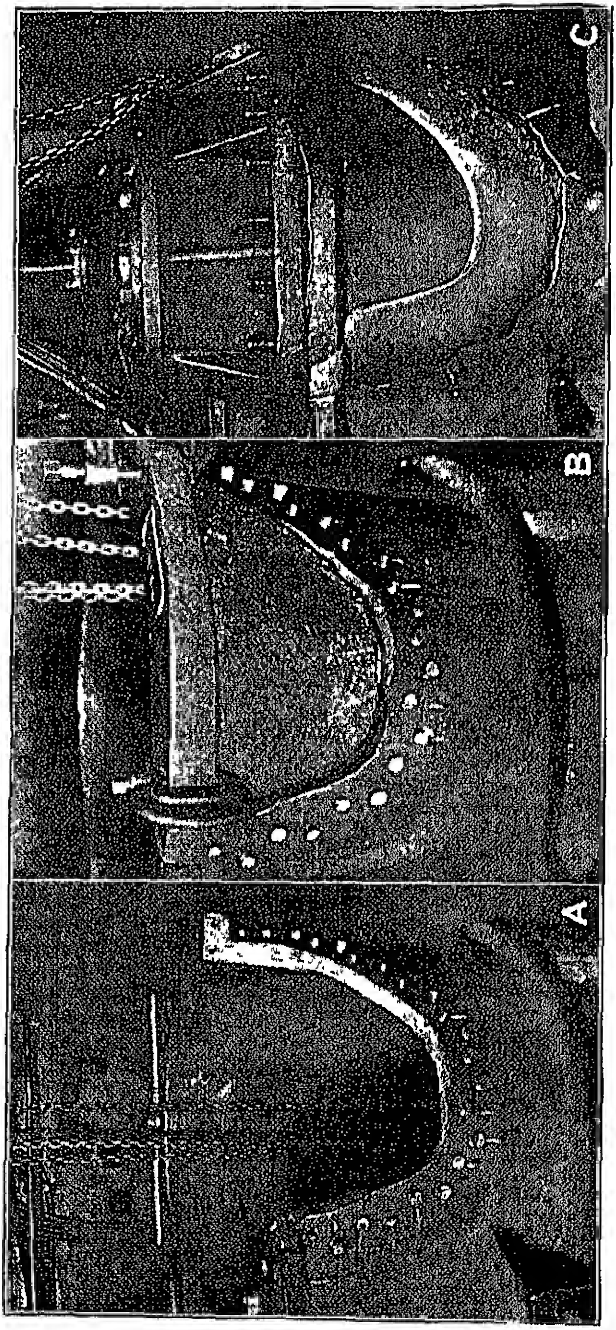


FIG. 113.—Broken High-Pressure Cylinder of U. S. S. "George Washington" and Method of Repairing.

unnecessary. But the work in these particular cases was of vital importance, due to the uses to which the vessels were to be put when in service, and also it was appreciated that this exhibition of a new application of the art in the marine engineering world required that the demonstration be satisfying, not only to the mind of the engineer, but to the eye, and ear, and when any engineer looked at that band of metal and sounded it with a hammer, he could not be but satisfied that the strength was definitely there and that the method of padding could be used in most of the situations which would arise. This at least was the effect upon all the engineers who saw the actual work.

The metal was laid on in layers in such a manner as to take care of the contraction in cooling. Each successive layer was cleaned with a wire brush before the next layer was put on. It is in the keeping of the successive layers clean and in the laying on of the metal so as to take care of the contraction that the operator's ability comes in fully as much as it does in the handling of the apparatus. The cylinders were not removed, but were repaired in place. Thus the work of fitting was reduced to a negligible quantity, and the refitting of lagging was not interfered with by projections, other than the $\frac{5}{8}$-in. pad, which is laid over the studs for extra strength. It will also be noted that these repairs can be undertaken at any place where the vessel may be lying, either at her loading dock or in the stream, since such apparatus may be carried on barges, which can be placed alongside and wires run to the work.

In this work a part consisted of the caulking of the surface of the welds which prevents porosity and also locates any brittle spots or places where poor fusion of metal has been obtained. This permits the cutting out of the bad places and replacing with good metal. The tool used was an air caulking hammer operated at 110 lb. air pressure.

Strength of Cast-Iron Welds.—Capt. E. P. Jessop, U. S. N., personally tested many welds for tensile strength in which cast iron was welded to cast steel, and in but one case was there a failure to obtain practically the original strength. This case was due to an inexperienced operator burning the metal, and was easily detected as an inferior weld without the strength test being applied.

Much has been said about the effect of the heat of welding, upon the structure or strength of cast iron, and in this particular instance the Navy engineer who had direct charge of this work, made experiments to note if there were any deleterious effects on the iron resulting from the action of the weld and reported as follows:

"Scleroscopic investigation of the structure of the welds shows only a very slight vein of hard cast iron at the line of the weld, shot through with fingers of gray cast iron, while behind this area there was no heat effect whatever. The metal thus deposited was easily workable with hammer and chisel, file or cutting tool. Another very important feature is that with the use of the low voltage and absolute automatic current control of the Wilson system, there is a minimum of heat transmitted to the parts to be welded, this being practically limited to a heat value absolutely necessary to bring the electrode and the face of the metal to be welded into a semi-plastic state, thus insuring a perfect physical union, and in accomplishing this result neither of the metals suffers from excessive heat, and there is absolutely no necessity for pre-heating. Neither are there any adverse results from shrinkage following the completed work owing to a minimum amount of heat being transmitted to the repair parts, thus avoiding the possibility of distortion of parts through uneven or excessive shrinkage strains that are very common where pre-heating is necessary or excessive heat is used for fusing metals."

A, Fig. 114, shows the damage done to the first intermediate cylinder of the U. S. S. "Pocahontas," formerly the "Prinzess Irene." The damage to this cylinder, it will be noted, was more destructive than to that of the "George Washington," rendering the repairs much more difficult.

B shows the steel section in place ready for welding, with the surfaces properly V'd out and with a staggering row of steel studs adjacent to the welding edge of the cylinder section.

C shows the complete job with the extra band or pad of metal completely covering the studs on the cast-iron section. These bands or pads of metal are peaned or worked over with a pneumatic hammer to insure protection against porosity of metal.

Had either or both of these cylinders been fractured on the lines shown of the cast-iron sections, and none of the parts removed, then the surfaces or edges of all lines of fracture would have been V'd out, and the weld made of the two cast-iron surfaces in the same manner that the cast steel was welded to the cast-iron cylinder proper.

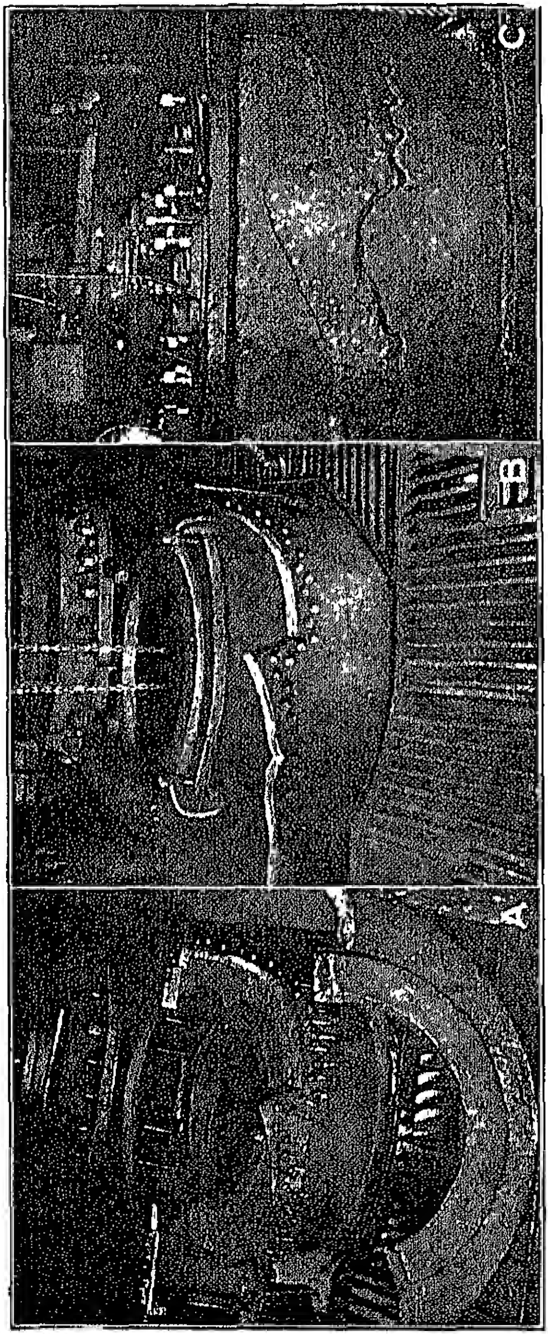


FIG. 114.—Break and Repair of First Intermediate Cylinder of the U. S. S. "Pocahontas"

OTHER SHIP WORK

In line with the foregoing J. O. Smith, writing in the *American Machinist*, Jan. 22, 1920, says: When the matter of welding in connection with ship-construction is considered, immense possibilities immediately suggest themselves. It has been definitely determined by exhaustive technical study and experiment that welding can be satisfactorily employed in ship construction, that ship plates joined by welding will be as strong or stronger than the original metal at the welded joint, and that welding can be employed for ship-construction work at a saving of 25 per cent. in time and 10 per cent. in material, as compared to riveting.

In actual figures, as determined by experiments of the Emergency Fleet Corporation's electric welding committee, it was determined that, by welding, in the case of a 9500-ton ship the saving in rivets and overlapped plates would amount in weight to 500 tons, making it possible for the ship to carry 500 tons more cargo on each trip than would be possible if the ship plates, etc., had been riveted, instead of welded.

An investigation by the same committee has definitely established the following points: That electric-welded ships can be built at least as strong as riveted ships; that plans for ships designed to be riveted can easily be modified so as to adapt them for extensive electric welding, and thus save considerably in cost and time for hull construction; that ships especially designed for electric welding can be built at a saving of 25 per cent. over present methods and in less time.

An electrically welded ship is credited with many advantages over a riveted ship. In a 5000-ton ship, about 450,000 rivets are used. A 9500-deadweight-ton ship requires 600,000 or 700,000 rivets. By the welding process the saving in labor on the minor parts of a ship is reckoned at from 60 to 70 per cent. on the hull, plating and other vital parts; the saving in labor, cost and time of construction by welding is conservatively placed at 25 per cent.

That electric welding will some day largely replace riveting is also the judgment of the electric-welding committee which is composed of many leading experts in both the electrical and metallurgical branches of the welding field.

Considerable investigation of the subject of welding instead of riveting has been made in England by Lloyd's Register of Shipping, particularly with regard to formulating rules for application to the electrical welding of ships. As a result of the investigations and experiments made by the technical staff, it was determined that the matter had assumed such importance as to warrant the formulation of provisional rules for electrically welded vessels, and these have been issued, for the guidance of shipbuilders, by Lloyd's Register.

The experiments conducted in England followed three well-defined lines of investigation: Determination of ultimate strength of welded joints, together with their ductile properties; capability of welded joints to withstand alternating tensile and compressive stresses, such as are regularly experienced by ships; and a microscopic and metallurgical analysis to determine if a sound fusion was effected between the original and added metal.

It was determined that the tensile strength of the welded joints was from 90 to 95 per cent. of the original plates, as against a strength of from 65 to 70 per cent. in riveted joints, showing a margin of 25 per cent. increased strength in favor of the welded joints.

The result of the tests of the elastic properties of welded joints determined that there was a slight difference in favor of the riveted joint, but the art of welding has made such great strides recently that it is now believed entirely possible to make a welded joint in ship plates that will stand as great a number of reversals of stresses as a riveted joint.

Microscopic and metallurgical analyses have determined that a good, solid, mechanically sound weld was made between the original and the added metal, the two having been fused together so perfectly that no line of demarcation could be seen.

The rules so far promulgated by Lloyd's (January, 1920), have been necessarily of a tentative nature and will no doubt be modified and enlarged from time to time in view of the experience that will be gained after welded ships have been in service for a time.

It does not require a great deal of imagination, however, to enable anyone to form the opinion that the shipbuilding industry is on the eve of great modifications in constructional

lines, and the guidance given by the tests and comparisons so far made will undoubtedly lead to important, radical departures and developments.

In addition to the increased cost of riveting as compared to welding, it is practically always true that there is a certain percentage of imperfectly fitted rivets, that do nothing more than add weight to the ship. The main purpose of a rivet, of course, is to bind two or more thicknesses of material together, but if the rivet is bent, loses part of its head in the riveting process or otherwise fails in its proper purpose, there is no method by which such faults can be corrected after the rivet cools. If the importance of the riveted part requires a perfect joint, the faulty rivets must be removed entirely, and this is frequently a time-killing, expensive course to follow. When it is considered that a 5500-ton ship requires approximately 450,000 rivets to bind the various parts and plates and also that a certain percentage of these rivets is not fulfilling the purpose for which they were put into the ship, it is quite evident that practically every ship is burdened with a good-sized load of dead, useless weight. Such defective rivets are, in fact, more than a useless weight, in that they are a menace to the ship, for while they have been built into the ship for a purpose, and are supposed to be fulfilling that purpose, there is no telling how much the ship has been weakened structurally by their failure.

There are many reasons for defective rivets, and one of the greatest of them is the inaccessibility of the parts to be riveted and the consequent difficulty on the part of the riveter in putting the rivets properly in place. Another reason is that there is no certainty that rivets are at a proper, workable temperature; in consequence of which if they are too cold, the pneumatic hammer now generally used in riveting is unable to round off the end of the rivet properly, so as to insure a proper binding together of the plates the rivet is supposed to hold.

In many cases, when such faulty rivets are discovered, the present-day method is to weld such defective spots, which immediately brings up the natural question as to why the plates should not be welded in the first place.

The ability of a welder, using a direct-current, low-voltage

arc with automatically regulated current to make sound mechanical welds in cramped, confined spaces, on overhead

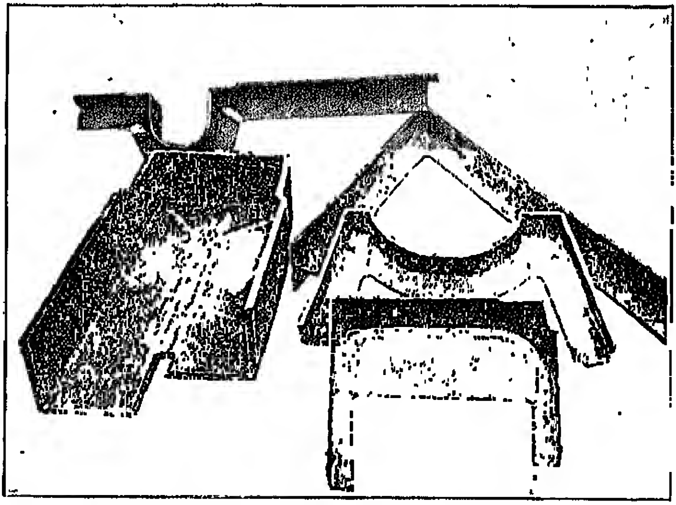


FIG. 115.—Welded Parts for Ships.

or vertical walls, in fact, anywhere a man and a wire can go, naturally suggests that welding ship plates together should be the primary operation in shipbuilding; and from present in-

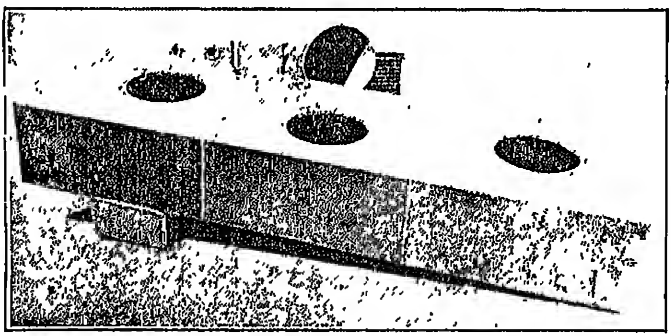


FIG. 116.—Welded Fuel-Oil Tanks.

dications and the trend of current events, it seems more than likely that this will be the outcome in the near future.

Examples of various ship parts welded by the metallic arc

are shown in Fig. 115. In Fig. 116 is shown a welded tank and in Fig. 117 a welded steel-plate, 4×7 ft. condenser.

Reason for Successful Welds.—In connection with the work just described, the Wilson people claim that their success, and the uniformity of their welds, was made possible because their apparatus enables the welder to control his heat at the point of application. In welding there is a critical temperature at which steel can be worked to give the greatest tensile strength, and also ductility of metal. By raising the heat 15 or 20 amp. above this critical amperage a fracture of the

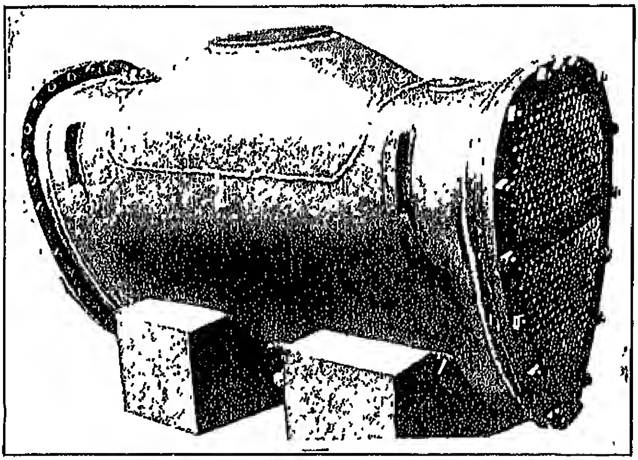


FIG. 117.—Welded Steel-Plate Condenser. No Rivets in Its Construction. Size 4 × 7 Ft.

weld will show segregation of carbon and slag pockets, which, of course, weakens the weld. If the amperage is decreased from the critical temperature, a fracture of the weld will show that the metal has been deposited in globules, with many voids, which proves that the weld has been made with insufficient heat. This shows, they claim, that with a fluctuating amperage or voltage, it is impossible to obtain uniformly high-grade welds.

In addition to their apparatus they use special electrodes for various jobs. One electrode is composed of a homogeneous alloy combined with such excess of manganese as will compensate for losses while passing through the electric arc, thus

insuring a substantial amount of manganese in the welded joint which is essential to its toughness. They also claim to have

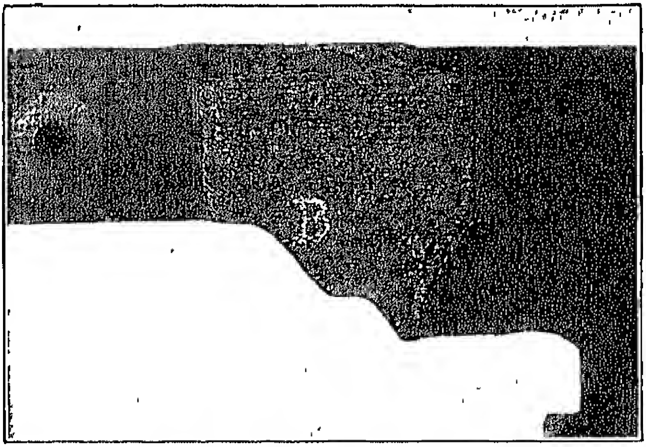


FIG. 118.—Welded Locomotive Frame.

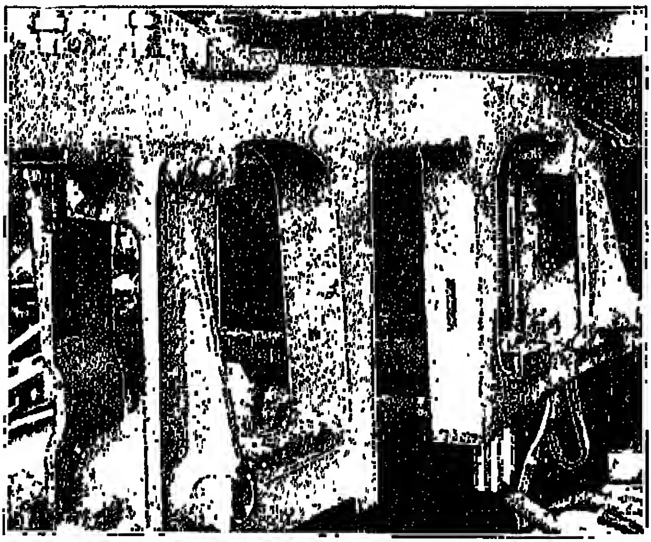


FIG. 119.—Built Up Pedestal Jaw.

a manganese copper alloy welding metal electrode which is composed of iron homogeneously combined with such an excess of manganese and copper over the amount lost in the

are as will insure to the welded joint a substantial additional degree of toughness and ductility.

Their special electrodes run in grades, corresponding in sizes to the gage numbers of the American Steel and Wire Co.'s table. Grade 6 is for boiler work; grade 8 can be machined; grade 9 is for engine frames, etc.; grade 17 is for filling castings and grade 20 is for bronze alloys, bells, etc. The tensile strength of welds made with these electrodes is

Fig. 120.—At Work on a Locomotive Frame.

given as from 40,000 to 60,000 lb. The wire furnished is usually gage 9, approximately $^5/_{32}$ in. in diameter. This is shipped in coils of about 160 lb. No fluxes are used with any of these electrodes.

Locomotive Work.—The railroad shops of the United States were among the first to use arc welding to any extent. In fact, without the great amount of experimental work done in railroad shops, the use of the arc in the repair of the damaged ships by welding would have been practically impossible.

In some cases of locomotive repair there is a big question in the minds of engineers as to whether replacement is to be insisted upon or welding allowed. Rules have been drafted by a number of railroad associations, but at present no uniform rules covering all cases are in existence. However, on certain

FIG. 121.—Welding Cracked Driving Wheel Spokes.

classes of work there is no real question that welding is the quicker and better way.

In Fig. 118 is shown a repair on a steel locomotive frame, the size of the smaller section being 5×6 in. The broken ends were beveled off on each side and a piece of steel bar was welded in between the ends, thus saving considerable time and electrode material.

Fig. 119 shows how the worn face of a pedestal jaw was built up by means of the "plastic-arc" process.

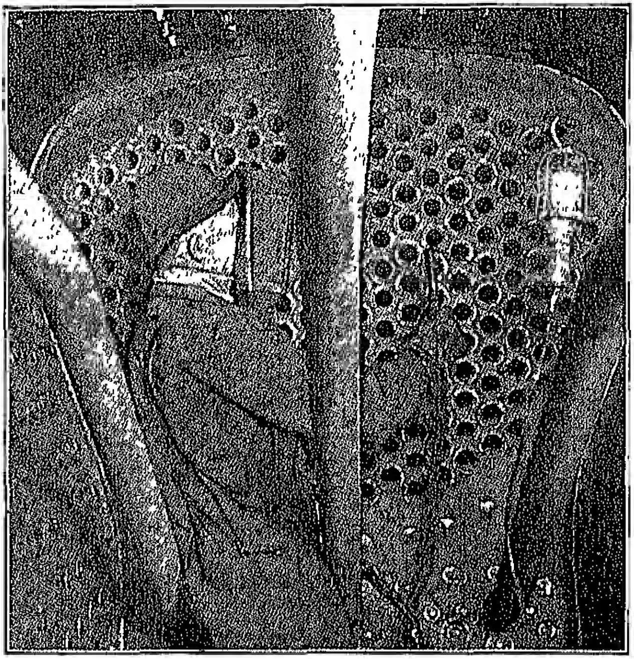


FIG. 122.—Welding Locomotive Boiler Tubes to Back Sheet.

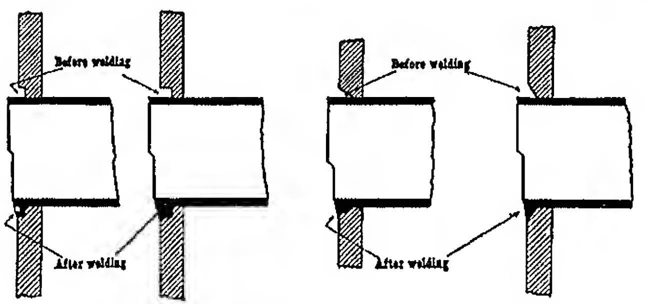


FIG. 123.—Method of Welding Boiler Tubes to Sheet.

Another frame-welding job is shown in Fig. 120. The weld was 3 in. high, 4½ in. wide and 4 in. deep. One man finished the job with a Westinghouse outfit in about 5 hours.

Fig. 121 shows the welding of a locomotive cast-steel drive wheel. Four spokes were cracked.

Fig. 122 shows the welding of locomotive boiler tubes to the back flue sheet. All of these jobs were done by the "plastic-arc" process, and represent a very small portion of the kinds of jobs that may be done in a railroad shop.

The method of welding flue ends to the sheets as suggested by Westinghouse is shown in Fig. 123.

H. A. Currie, assistant electrical engineer, New York Central R.R., writing in *Railway Age*, says:

The saving in our locomotive shop since electric welding was installed can hardly be calculated and the additional mileage that is obtained from locomotives is remarkable. This is mainly due to the following:

"A. Greater permanency of repairs.

"B. Shorter periods in the shop, giving additional use of equipment.

"C. Existing shop facilities permit taking care of a larger number of locomotives than originally expected. Shop congestion relieved.

"D. The use of worn and broken parts which without electric welding would be thrown in the scrap pile.

"E. The time required to make repairs is much less and requires fewer men.

"F. A smaller quantity of spare parts carried in stock.

"The following is a brief description of some of the work done on steam locomotives:

"**Flue and Fire Box Welding.**—The most important results are obtained by welding the boiler tubes to the back flue sheet. The average mileage between shopping on account of leaky flues on passenger locomotives was 100,000 miles. This has been raised to 200,000 miles with individual records of 275,000 miles. For freight this average has been raised from 45,000 to 100,000 miles. At the time of locomotive shortage this effect was of inestimable value.

"Good results have been obtained without the use of sandblast to prepare the tubes and sheets. The engine is either fired or an acetylene torch used to burn off the oil, after which the metal is cleaned off with a scraping tool. The ferrules are of course well seated and the tubes rolled back. The boiler is filled with water in order to cool the tubes, which having a much thinner cross-section than the sheets, would overheat sufficiently to spoil the weld or burn the tube. The metal is then laid on, beginning at the bottom of the bead and working to the top. Records show that the time to weld a Pacific type locomotive boiler complete is 12 hours.

"A variety of repair work is readily accomplished in locomotive fireboxes such as the welding of crown-sheet patches, side-sheet cracks and the reinforcing and patching of mud rings. Smokebox studs are also welded on.

"**Side Frames, Couplers and Wheels.**—Cracked main members of side

frames are restored and wearing parts built up and reinforced. Because of accessibility no special difficulties are encountered in this work. Formerly this work was chiefly done with oil welding and some acetylene and thermit work, but it was very much more expensive as the preparation required considerable effort and took a good deal of time.

"Fifty per cent of the engines passing through the shops have worn and broken coupler parts and pockets. By welding an average saving of about $15 per coupler is made. It costs about $30 in material and labor to replace a coupler and only $4 to repair the average broken coupler. The scrap value is about $5.

"Great success has resulted from various repairs to steel wheels and tires. Flat spots have been built up without removing the wheels from the locomotives, thus effecting a great saving in time and money. Building up sharp flanges saves about ⅝-in. cut off the tread, which when followed through means about $30 for a pair of wheels, a great increase in tire life and reduction in shop costs.

"Cylinders.—The most interesting feature developed by arc welding was the accomplishment of cast-iron welding. The difficulty in welding cast iron was that while the hot metal would weld into the casting, on cooling the strain would tear the welded portion away from the rest of the casting. Small studding was tried out with no success. Not until wrought-iron studs, proportioned to the sectional strength of the casting, were used did any satisfactory welds turn out. Studding of this large size was looked upon with distrust, as it was thought that the only weld was to the studding. This naturally meant that the original structure was considerably weakened due to the drilling. This, however, was not the case. The large studding was rigid enough to hold against the cooling strains and prevented the welds in the casting from pulling loose, thus adding the strength of all the welded portion to that of the studs. In most cases where external clearance will permit, sufficient reinforcing can be added to more than compensate for the metal removed in drilling for the studs.

"Perhaps more skill is required for this class of welding, but with a properly prepared casting success is certain. A concrete case of the economy effected in welding a badly damaged cylinder on a Pacific type engine is as follows:

WELDED JOB	
Cost of welding broken cylinder, labor and material	$125.00
Length of time out of service, 5 days at $20 a day	100.00
Scrap value of old cylinder (8,440 lb. at 2.09 lb.)	177.00
Total	$402.00
REPLACED CYLINDER	
Cost of new cylinder ready for locomotive	$1,000.00
Labor charge to replace it	150.00
Locomotive out of service 18 days at $20 a day	360.00
	$1,510.00
Less cost of welding	402.00
Total saving	$1,108.00

"Some twenty-five locomotives have been repaired in this way at one shop alone.

"Many axles are being reclaimed by building up the worn parts. These are tender and truck axles which are worn on the journals, wheel fits and collars. The saving is about $25 per tender axle and $20 for truck axles.

"The range of parts that may be repaired or brought back to standard size by welding is continually expanding. Wearing surfaces on all motion links and other motion work, crosshead guides, piston-rod crosshead fits, valves and valve seats, air, steam, sand and other pipes, keys, pins and journal boxes have all been successfully welded.

"A large saving is effected in welding broken parts of shop tools and machinery. During the war this was of untold value, as in some cases it was out of the question to get the broken parts replaced.

"**Training of Operators.**—The training of arc welders is most important. Success depends solely on the men doing the work. They must be instructed in the use of the arc, the type, size and composition of the electrode for various classes of work and the characteristics of the various machines they will be called upon to use. A properly equipped school for teaching these matters would be a valuable adjunct for every railroad. Manufacturers of equipment have recognized the importance of proper instruction and have equipped schools where men are taught free of charge.

"**Supervision.**—Co-ordinate with the actual welding is intelligent supervision. The scope of the supervisors should include preparation of the job for the welder and general oversight of the equipment in the shop.

"Thus the duties of the inspector might be summarized in the following points:

"1. To see that the work is properly prepared for the operator.
"2. The machines and wiring are kept in good condition.
"3. Proper electrodes are used.
"4. To inspect the welds in process of application, and when finished.
"5. To act as adviser and medium of interchange of welding practices from one shop to another.

"In work such as flue welding and industrial processes which repeat the same operation, piece-work rates may be fixed. For varying repair jobs this method cannot be used with justice either to the operator or the job.

"Bare electrodes are used almost exclusively, even for a.c. welds. Whenever a new lot of electrodes is received it is good practice to make up test-piece samples and subject them to careful tests and analysis.

"The sizes of electrodes and uses to which they are put are shown in the table.

Size	Type of Work
1/8 in.	Flue welding.
5/32 in.	For all repair work, broken frames, cylinders, etc.
7/32 in.	For building up wearing surfaces.

"General Rules.—In closing it will be well to point out a few general rules required to obtain satisfactory welds.

"1. The work must be arranged or chipped so that the electrode may be held approximately perpendicular to the plane of welding. When this cannot be accomplished the electrode must be bent so that the arc will be drawn from the point and not the side of the electrode. For cast iron the studding must be properly arranged and proportioned. The surfaces to be welded must be thoroughly clean and free from grease and grit.

"2. The proper electrode and current value must be selected for the work to be done.

"3. The arc should be maintained as constant as possible.

"4. For nearly all work the prepared surface should be evenly welded over and then the new surfaces welded together.

"5. Suitable shields or helmets must be used with proper color values for the lenses.

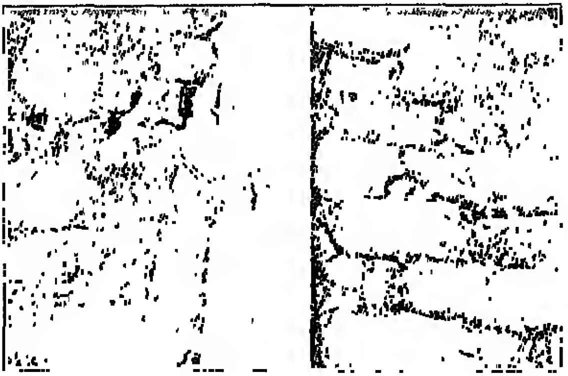


Fig. 124.—Built Up Cupped Rail Ends.

"For locomotive work a good operator will deposit an average of 1 to 1¼ lb. of electrode per hour. The limits are from 1 to 2 lb. High current values give more ductile welds, in proportion to deposited metal. For locomotive welding the great advantage of the arc over thermit, oil or acetylene welding is that preparation at the weld is all that is necessary. No secondary preparation for expansion of the members is necessary. This is the great advantage in welding side frames."

Considerable welding work is done in building up worn track parts. Fig. 124 shows the building up of cupped rail ends and Fig. 125 shows manganese-steel cross-over points built up by arc welding. Such repairs have stood long and hard service.

Other Welding Work.—In the steel mills a great deal of welding is required to build up worn roll or pinion pods. Fig. 126 shows a welder at work building up worn pods with a carbon arc and filler. Fig. 127 shows a finished job with the

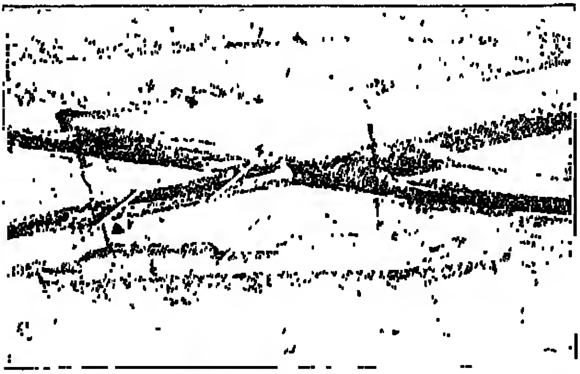


FIG. 125.—Built Up Manganese Steel Cross-Over Points.

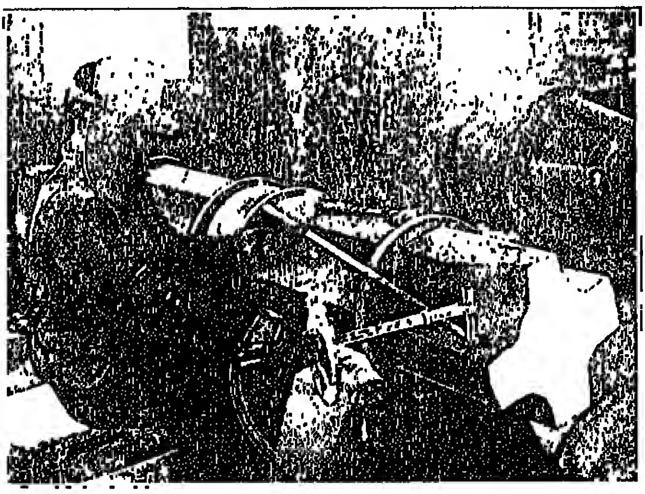


FIG. 126.—Building Up Worn Roll Pods.

worn part outlined in white. The cost of repairing four ends (two pinions) was $170. The pinions cost $1,000 each.

The way a five-ton roll housing was repaired is shown in Fig. 128. In this case a heavy steel plate was bolted over the crack and welded as indicated. It might have been all

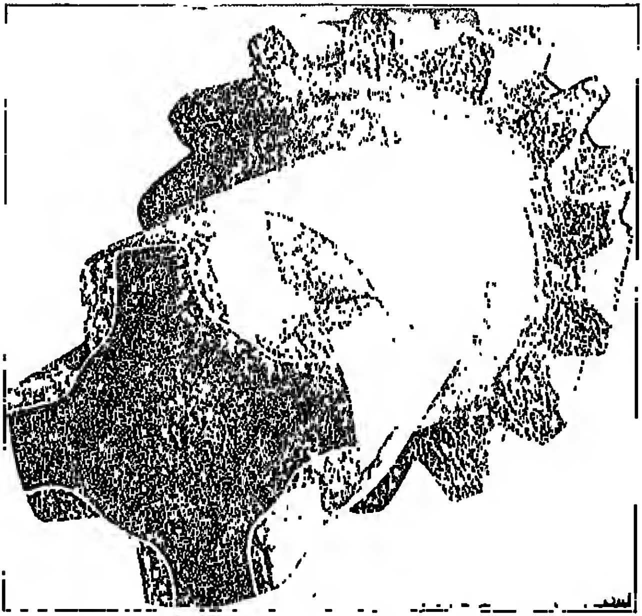


FIG. 127.—Finish-Welded Pinion Pods.

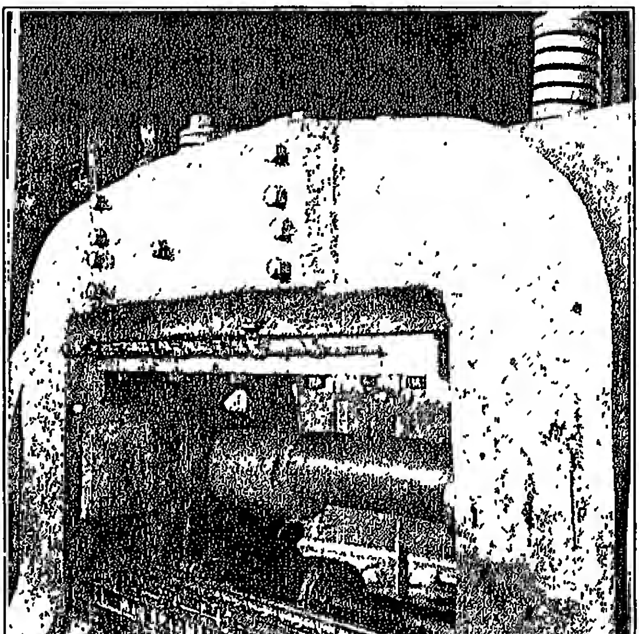


FIG. 128.—Repaired 5-Ton Roll Housing.

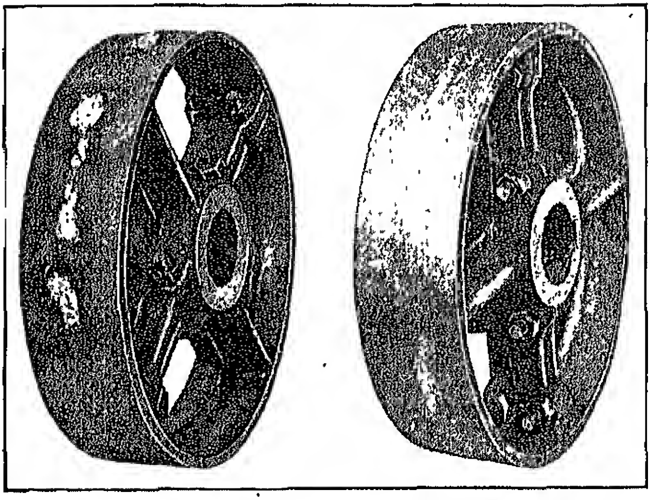


FIG. 129.—Welded Blowholes and Machined Pulley.

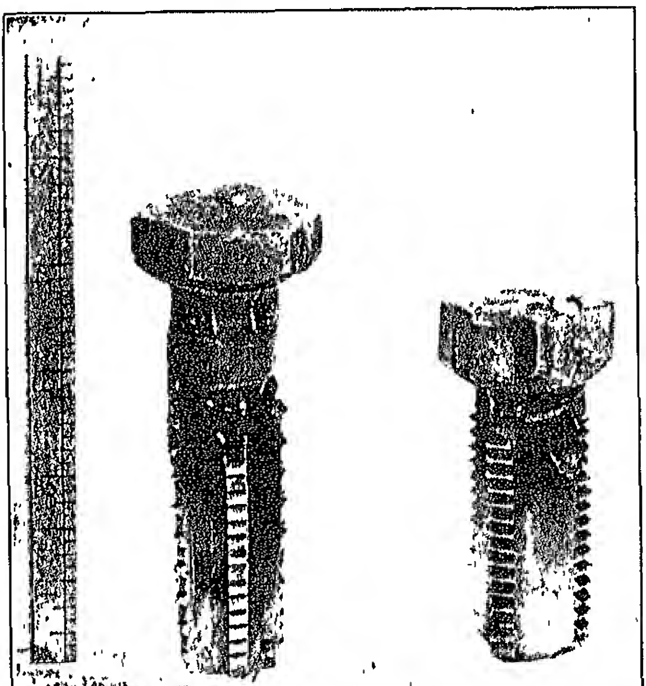


FIG. 130.—Method of Welding Taps Broken Off in the Hole.

right to weld direct, but in this case, owing to the heavy duty required, it was thought best to play safe and use the steel plate.

Welded blowholes in the rim of a large pulley are shown at the left in Fig. 129. At the right the pulley is shown after machining.

Broken taps may be removed if a nut is welded on as shown in Fig. 130. In doing work of this kind, the arc is struck on top of the tap and kept there until the metal is built up above the top of the hole. An ordinary nut is then laid over it and welded fast. If the arc is kept on the tap the metal may run against the sides of the hole but will not adhere, but care must be exercised so as to not let the arc strike the sides of the hole.

ELECTRIC CAR EQUIPMENT MAINTENANCE

The growing possibilities of electric welding processes in connection with the maintenance of rolling stock and other railway equipment have been a source of amazement to every electric railway man who has come into contact with the practice, says the *Electric Railway Journal*. This began with the repair of broken members of the various parts of electric car equipment and has led to its use in a still larger field, which includes the building up of worn surfaces of steel parts which previously would have been headed for the scrap heap. The accompanying illustrations show some parts of electric car equipment which have been reclaimed by electric welding in the shops of several electric railways. This work was begun at a time when it was very difficult to obtain railway equipment parts and it has resulted in large savings and has enabled the equipment to be returned to service so quickly, that the work is being extended and used for defective-part repair which previously would not have been considered.

The United Traction Company, Albany, N. Y., constructed a special concrete building for its electrical repair work a year ago. A separate room was built at one end of this building and arranged particularly for electric welding, and all important details were incorporated in the design to fit this room for the purpose to which it was to be put. The building is a concrete structure throughout and the floor of the welding room is also

of concrete. In dimensions this room is about 10 ft.×30 ft. and it is entirely inclosed and separated from the rest of the building.

As a safety precaution no one is allowed to enter the welding room while work is in progress. Two observation windows are provided on either side of the entrance door, in which colored glass has been installed as a protection to the eyes of the observer. Any one having business in the welding room

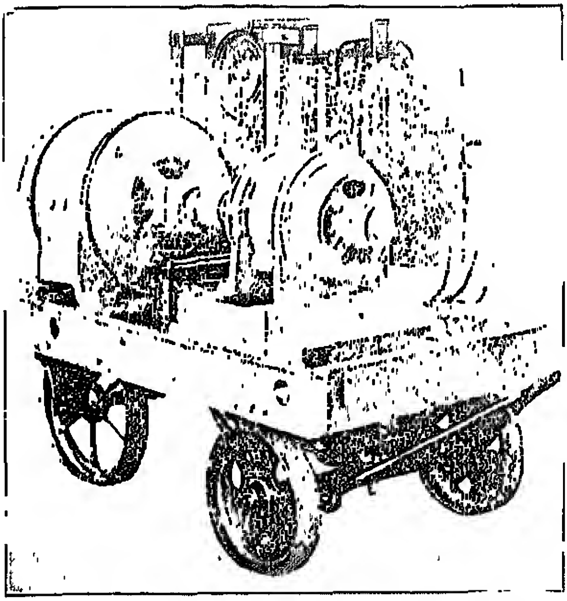


FIG. 131.—G. E. Portable Arc Welding Outfit.

can see when welding work is being done and thus avoid the danger of any harmful effect from the light of the arc.

The equipment at present in use in the welding room consists of a General Electric motor-generator set and an oxy-acetylene welding outfit, a welding table, convenient holders, masks and other welding equipment, and a chain hoist which travels on an I-beam the length of the room and also outside the entrance to pick up heavy work and facilitate the handling of heavy parts. Since the installation of this equipment the General Electric Company has developed a self regulating welding generator which constitutes a part of its single-operator

metallic electric arc welding equipment. This can be either stationary or portable and as it is self-contained it makes a very desirable combination. The generator has a two-pole armature, in a four-pole frame, with commutating poles, and generates sixty volts, open circuit. Bucking the shunt field is a series field, with taps brought out for different welding currents. As current flows from the main brushes through the series field windings it reduces the generator voltage to

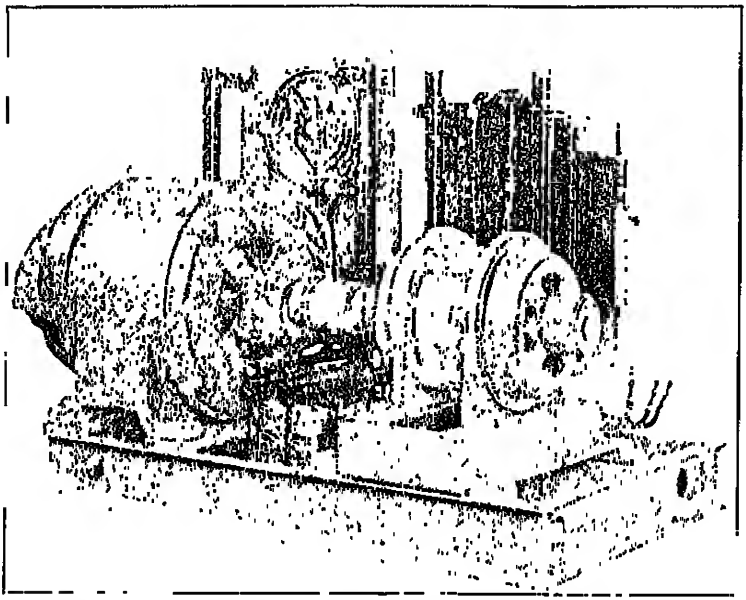


FIG. 132.—G. E. Generator Direct Connected to Motor, with Control Panel and Starter.

the proper welding value. Figs. 131 and 132 show two types of G. E. equipment.

One of the most important operations and one which shows far reaching economies in the work undertaken by the United Traction Company is the building up of worn armature shafts, as shown in Figs. 133 and 134. The pinion ends of the shafts were "chewed up" due to the wear of the keyways for the pinions. The defective ends of the shafts which were to be repaired were carefully cleaned of all oil and dirt and sufficient metal was welded on so that the shafts could be re-machined

and re-threaded. A large number of these armatures were all right except for the damage to the keyways, so that they were returned to service as soon as the shafts were re-machined

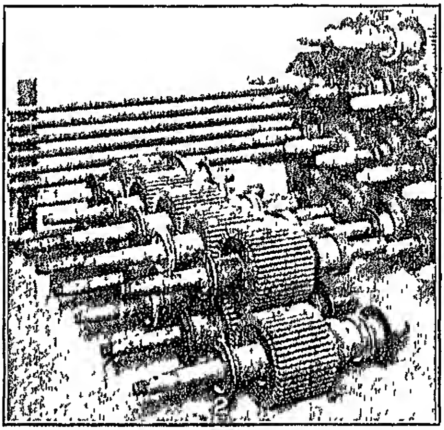


FIG. 133.—Worn Armature Shafts Before Welding.

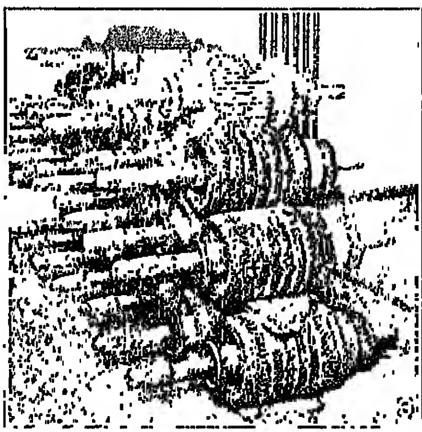


FIG. 134.—Armature Shafts After Welding.

and fitted. Others had damaged coils or grounded insulation and where it was necessary to re-wind an armature this was stripped before the welding operations took place. For weld-

ing operations of this character where a large amount of work is to be done which is similar in character the General Electric Company has developed an automatic welding machine described elsewhere. Its chief advantage lies in the increase

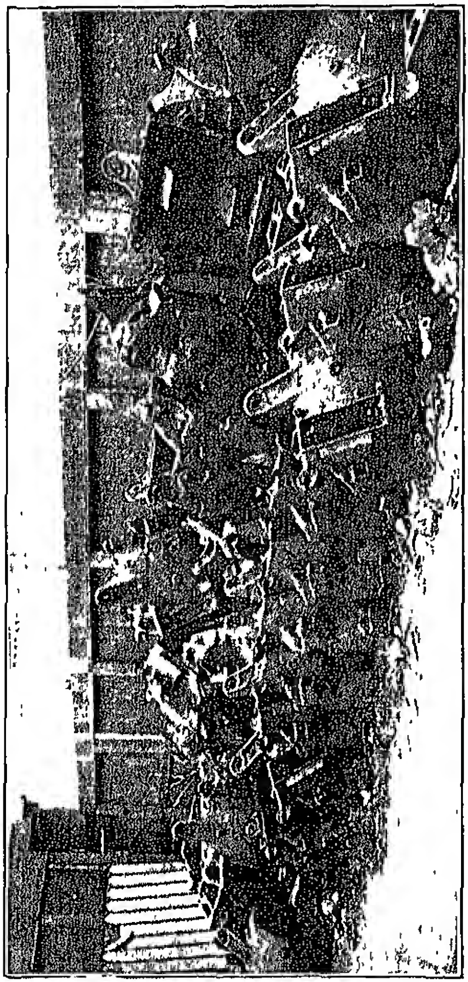


FIG. 135.—Motor Shells Which Were Reclaimed by Welding.

in speed which is possible and the uniformity of welds which results. In the work done at Albany the building up and re-machining of the shafts cost from \$3 to \$4 each, which was only about one-tenth of the cost of a new shaft. As local

conditions as to labor costs as well as the cost of energy vary to quite an extent detailed costs for the various operations are not included, but on roads which are performing this work and which have actual data regarding the purchase cost of the various parts, the savings which result offer convincing proof of the economies which can be effected with the use of electric arc welding.

Fig. 135 shows a pile of motor cases in the yards of the United Traction Company. Before the advent of the welding equipment many of these motor shells were intended for scrap

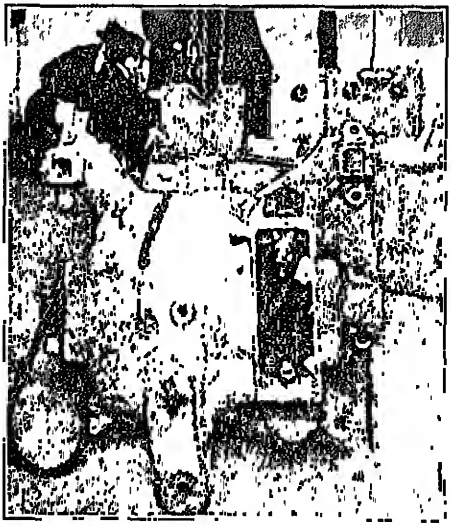


Fig. 136.—Repaired Gear-Case Suspension Arm.

due to various breakages and excessively worn parts. By the use of the welding equipment a large proportion of these have already been reclaimed.

The method employed in welding broken lugs or broken ends of motor shells consists first in fitting the broken parts together and lining them up in their correct position. The pieces are then welded at a few points so as to hold the broken parts in position and, where necessary, the fracture is cut out "V" shape to provide additional space for the welding metal. Much of the success which has been obtained in this class of work at Albany is attributed to the use of studs for inter-

locking the metal which is added to the broken parts. Holes for the ⅝-in. studs are drilled and tapped at several points adjacent to the break and the studs are so inserted as to extend above the motor shell to about the same height as the thickness of the additional metal to be added. The deposited

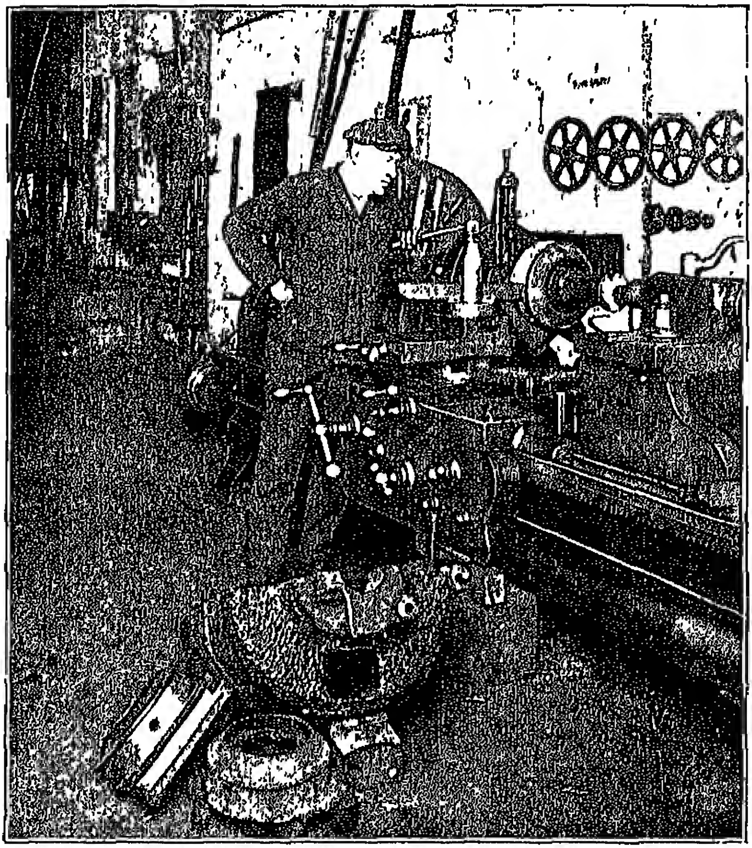


FIG. 137.—Broken Cast-Iron Motor Shell and Axle Housings Repaired by Electric Welding (Case Broken in Twelve Pieces).

metal is then allowed to bridge over these studs in welding and so obtains additional support which helps to strengthen the weld. In the illustration Fig. 136 showing repairs made to a broken gear-case suspension arm, one of these studs can be seen projecting from the casting.

As an example of what can be accomplished, in repairing broken shells, the illustration Fig. 137 showing a welded end of a motor shell alongside a lathe, is an extreme case. This motor shell was broken in twelve pieces and from the illustration it will be seen that nearly the entire end was welded.

Another record job made in the shop of the United Traction Company was the welding of a truck bolster. The car, under which was a truck with a broken bolster, was brought to the shop and placed on a track adjacent to the welding room.

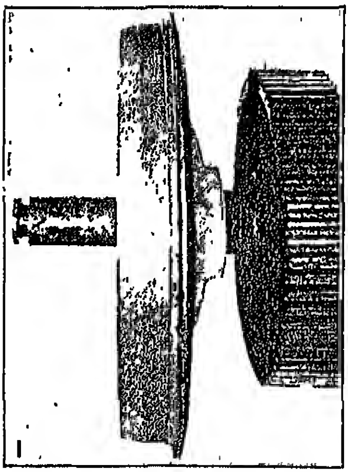


Fig. 138.

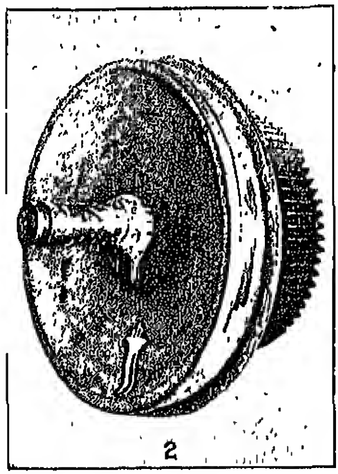


Fig. 139.

Fig. 138.—Wheel Turned Down Ready for Welding. Note Thinness of Flange.

Fig. 139.—Flange Built Up Ready to Be Shaped in Wheel Lathe.

The car body was jacked up and the bolster was repaired in approximately eight hours. The work was started at 9 o'clock after the morning rush hour and the car was ready for service again at 5.15 P.M.

In addition to the class of work illustrated as being done by the United Traction Company other interesting work is reported from various electric railways showing what has been accomplished. The Spokane & Inland Empire Railroad has done some work in reclaiming wheels with sharp flanges. Three views are given to illustrate the methods used. The

first of these, Fig. 138, shows a wheel with the flange turned down ready to receive new metal. The second Fig. 139 shows the flange with a new layer of welded metal. The third, Fig. 140, shows the finished wheel after it has been machined. After the new metal has been added the flange is merely shaped up with a forming tool. It is left quite rough in some cases, but as the practice has always been to put on new brake shoes when the wheels are repaired, the company has had no difficulty in wearing down the tread to a smooth contour.

A number of steam railways are at present reclaiming all of their cold rolled steel wheels which are slid flat or have

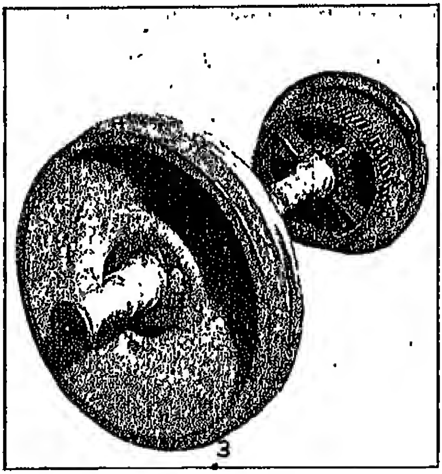


Fig. 140.—Finished Wheel Ready for Service.

flaked-out places, as well as those with sharp flanges. This operation creates quite a saving in itself as often the car is merely placed over the drop pit and the work can then be taken care of with the car fully equipped. By this method the car is withheld from service but a short period. In the welding of sharp flanges it is not contended by those who have had extended experience that the metal deposited will give the life of the parent material, but they agree that savings are created as a result of maintaining the car in service until such time as it is necessary to shop it for major repairs.

Another example of reclaiming electric car equipment is shown in the repairs to gear cases, Fig. 141. These are a

air sample of the repairs that are frequently found necessary. n this case patches are made of No. 10 sheet iron. In welding hese patches on, the operator first determines the size of the patch and outlines it with chalk on the old case. He then uilds up a layer of metal just outside the chalk mark. The atch is then laid on and welded to a layer of metal. In his way a tight and secure joint is made. As gear cases are requently covered with oil when they are brought in for epairs, they should be cleaned off as much as possible. In naking a patch that requires a bend, as in the case illustrated, he operator first welds the patch to the bottom of the case, hen heats the patch and bends it into shape.

Split Gears Made Solid.—Some electric railways which have

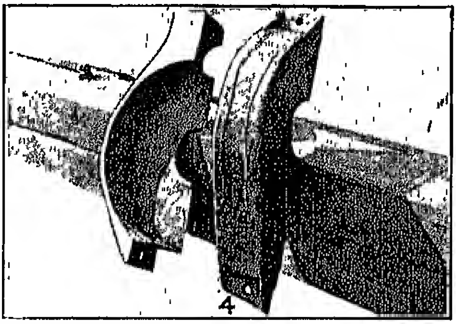


Fig. 141.—Gear Cases with Patches Welded On.

plit gears have found it advisable to change these to solid ears by welding and then to press them on the axles. Fig. 42 shows a gear which is being welded in this manner and 'ig. 143 an axle which has been built up so as to increase he gear seat. The method employed in welding the gears onsists, first, of cutting a "V" along the joint of the gear own to the bolts with a carbon electrode. The operator then uilds up with new metal and welds each bolt and fills up ie old keyways. This bore is then re-machined and a new eyway is cut. Broken teeth in gears are also easily repaired y welding.

Another use of welding which has been of benefit to electric ailways is in the maintenance of housings for the bearings f railway motors. Constant vibration and heavy jarring

causes the fit in the motor frame to become badly worn and many railways have used shims to take up this wear. A small layer of metal deposited by the electric arc and then machined to the desired dimensions provides a more serviceable job than

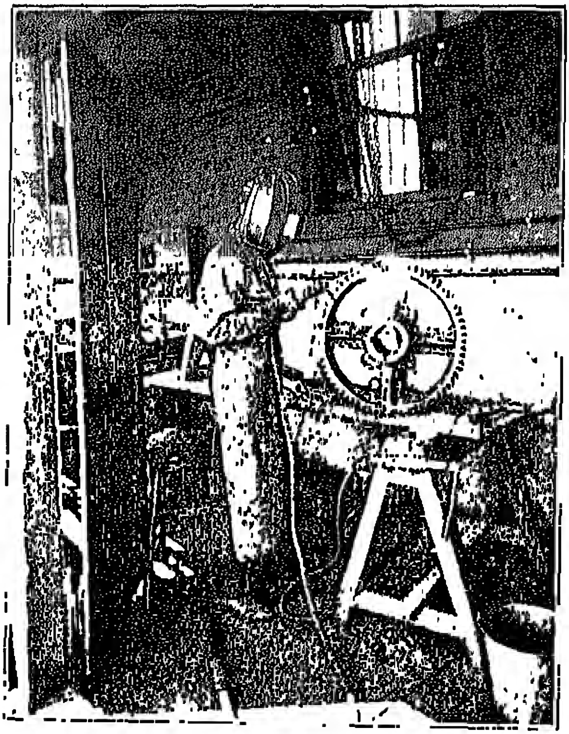


FIG. 142.

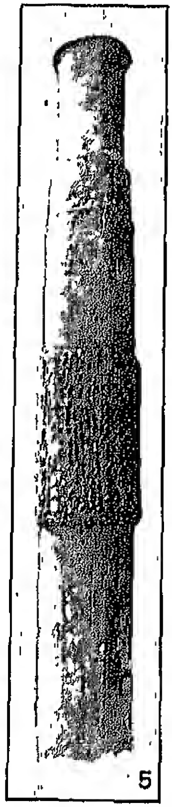


FIG. 143.

FIG. 142.—Welding Split Gear to Make a Solid One.
FIG. 143.—Axle Enlarged by Welding.

that of the shims, and when a tight fit is once secured, the wear is eliminated.

The filling in of bolt holes in various parts of the car equipment is another use which is showing far-reaching results. Heavy duty and constant vibration cause the holes to become worn, and the bolts then readily become loose and often fall

it. The filling in of these holes and their re-drilling takes ery little time and the cost is extremely low.

Some other welding operations which have been carried ut with success are these: side bearings which have become

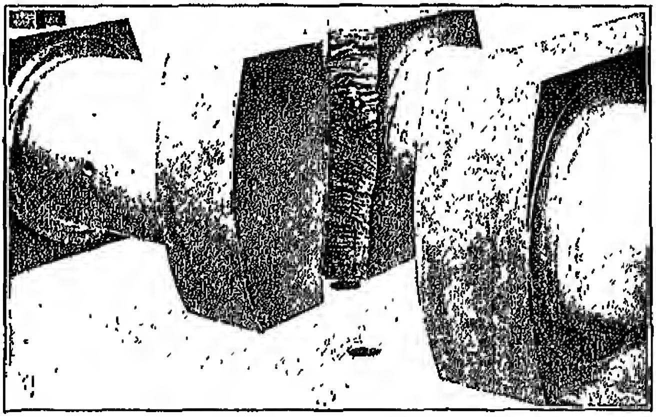


FIG. 144.—Crankshaft with Break Cut away for Welding.

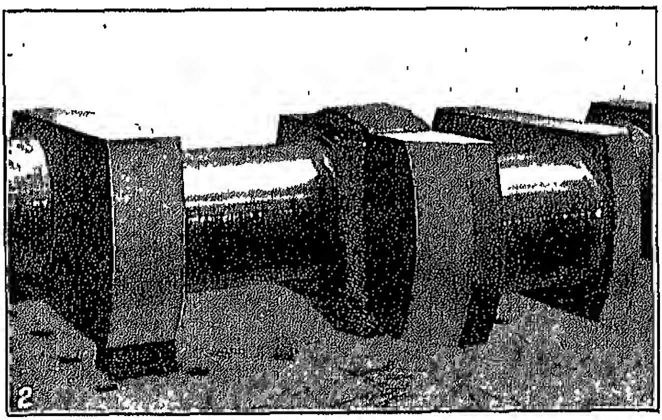


FIG. 145.—Completed Weld Before Trimming.

adly worn have been built up, brakeshoe heads and hangers ave been welded and truck side frames have been repaired n numerous cases. A large number of uses for electric welding re constantly presenting themselves to all railways. Enough istances have been cited to demonstrate the fact that the art

of welding has greatly increased the resources available for lengthening the life of equipment.

ELECTRIC WELDING A SIX-TON CRANKSHAFT

A six-ton crankshaft in the plant of the Houston Ice Co., Houston, Tex., broke through at one of the webs. As there was no means at hand to repair the break, the crankshaft was shipped to the Vulcan Iron Works, Jersey City, N. J., where it was electrically welded by the Wilson plastic-arc process.

The broken web, cut away preparatory to welding, is shown in Fig. 144, and the finished weld in Fig. 145. Owing to the size of the shaft, great care had to be exercised in keeping it in proper alignment. Fig. 146 shows it leveled and clamped to a large surface plate. A straight-edge is shown laid across the webs to assist the operator in judging and keeping the alignment.

A big feature in electric welding of this kind is that owing to the intense heat of the arc, no preheating is required as in using other methods. This, of course, greatly reduces the time required to complete a repair of this kind.

ARC-WELDING HIGH-SPEED TOOL TIPS

One large manufacturer has installed a Westinghouse arc-welding equipment for the sole purpose of making tools for turning heavy work. Ordinarily these tools are made from high-speed steel, and cost about $12 each. This manufacturer uses high-speed steel for the tip of the tool only, welding it to a shank of carbon or machine-steel, as shown in Fig. 147, and in this manner the tools are produced at a cost of $2 to $4.

For several weeks this plant has been turning out 240 welded tools a day, the men working in shifts of four, which is the capacity of this outfit.

The equipment consists of a 500-amp. arc-welding motor generator with standard control panel, and three outlet panels for metal-electrode welding, and one special outlet panel for the use of either metal or graphite electrodes. The special panel is intended to take care of special filling or cutting

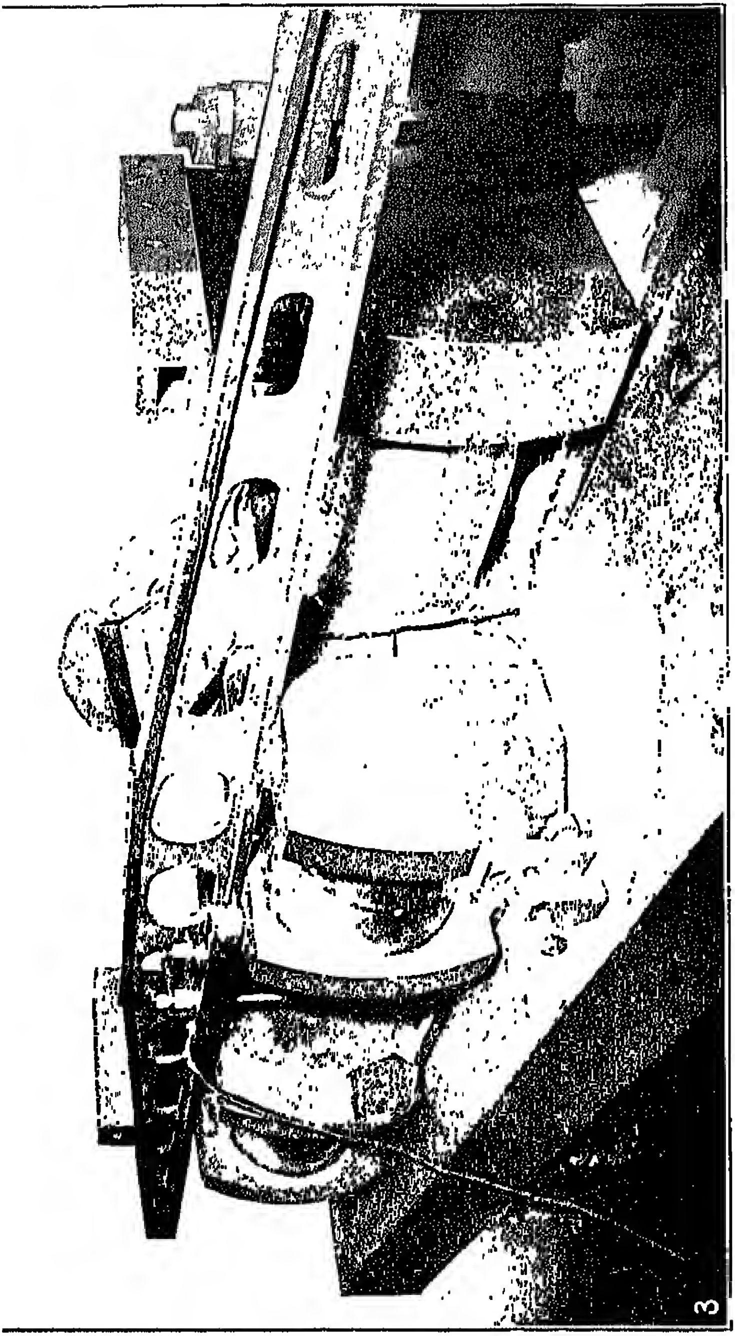


FIG. 146.—Method of Lining Up and Holding the Work

processes that may be necessary, but ordinarily it is used in the same manner as other panels for making tools. These panels are distributed about the shops at advantageous points.

For toolmaking, which involves the hardest grades of steel, a preheating oven is used, not because it is necessary for making a perfect weld, but because otherwise the hard steel is likely to crack from unequal cooling and also because pre-

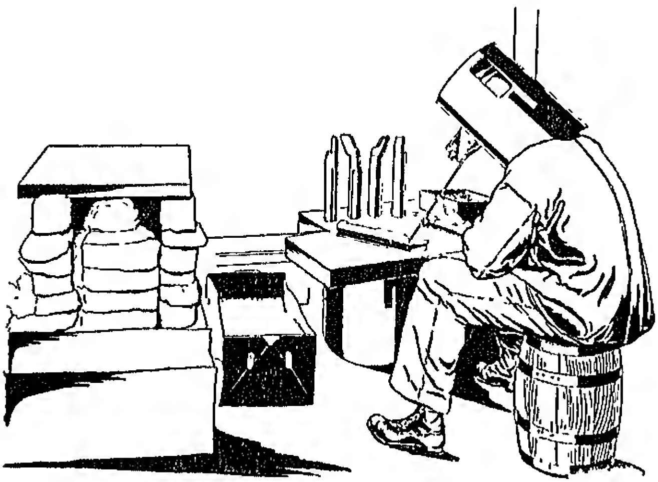


FIG. 147.—Welding High-Speed Tips Onto Mild Steel Shanks.

heating makes it easier to finish the tool after the welding process has been completed. For ordinary arc welding operations the preheating oven is never used.

ELECTRICALLY WELDED MILL BUILDING.

A small all-welded mill building was erected in Brooklyn in 1920 for the Electric Welding Co., of America, by T. Leonard MacBean, engineer and contractor. The structure is about 60 × 40 ft., and has four roof trusses of 40-ft. span supported on 88-in. H-beam columns fitted with brackets for a five-ton traveling crane. In its general arrangement the structure follows regular practice, but the detailing is such as to suit the use of welding, and all connections throughout are made by this process. A considerable advantage in cost and time is claimed for the welded connections, but in the present

nstance the determinative feature was not cost economy so nuch as the fact that the fabricated work could be obtained nore quickly by buying the plain steel members and cutting ınd welding them at the site instead of waiting for bridge shop leliveries.

The roof was designed for a total load of 45 lb. per sq. ft., of which about 30 lb. represents live load. Each truss weighs 1,400 lb. The chords are $4\times5\times\frac{3}{8}$-in. tees, while the web members are single $3\times2\times\frac{3}{8}$-in. angles. On the trusses rest 10-in. 15-lb. channel purlins spanning the 20-ft. width of bay. The columns are 8×8-in. H-beams, 19 ft. high, and the crane bracket on the inner face of the column is built up of a pair of rear connection angles, a pair of girder seat angles, and a triangular web plate, as one of the views herewith shows. Base and cap of the columns are made by simple plates.

All material was received on the job cut to length. A wooden platform large enough to take a whole truss was built as a working floor and the chord members were laid down on it in proper relative position to form a truss when connected. The top chord was made of a single length of tee, bent at the peak point after a triangular piece was cut out of the stem. At the heel points of the truss the stem of the top-chord tee was lapped past the stem of the bottom chord tee, and when the two members were clamped together the contact seams were welded; the seam of the stem at the peak was also welded shut. Then the web members were placed in position and clamped, and their connections to the chord welded. The metallic-electrode arc process was used and various welded parts are shown in Fig. 148.

Loading Tests.—When the plans for the building were submitted to the Department of Buildings, Borough of Brooklyn, the proposal to weld the connections was approved only with the stipulation of a successful load test before erection. This test was carried out March 20. Two trusses were set up at 20-ft. spacing and braced together, purlins were bolted in place, and by means of bags of gravel a load of 48 tons was applied. This was sufficient to load the trusses approximately to their elastic limit. No straining or other change was observable at the joints, and the test was considered in every respect successful. The deflection of the peak, 0.0425 ft., did not

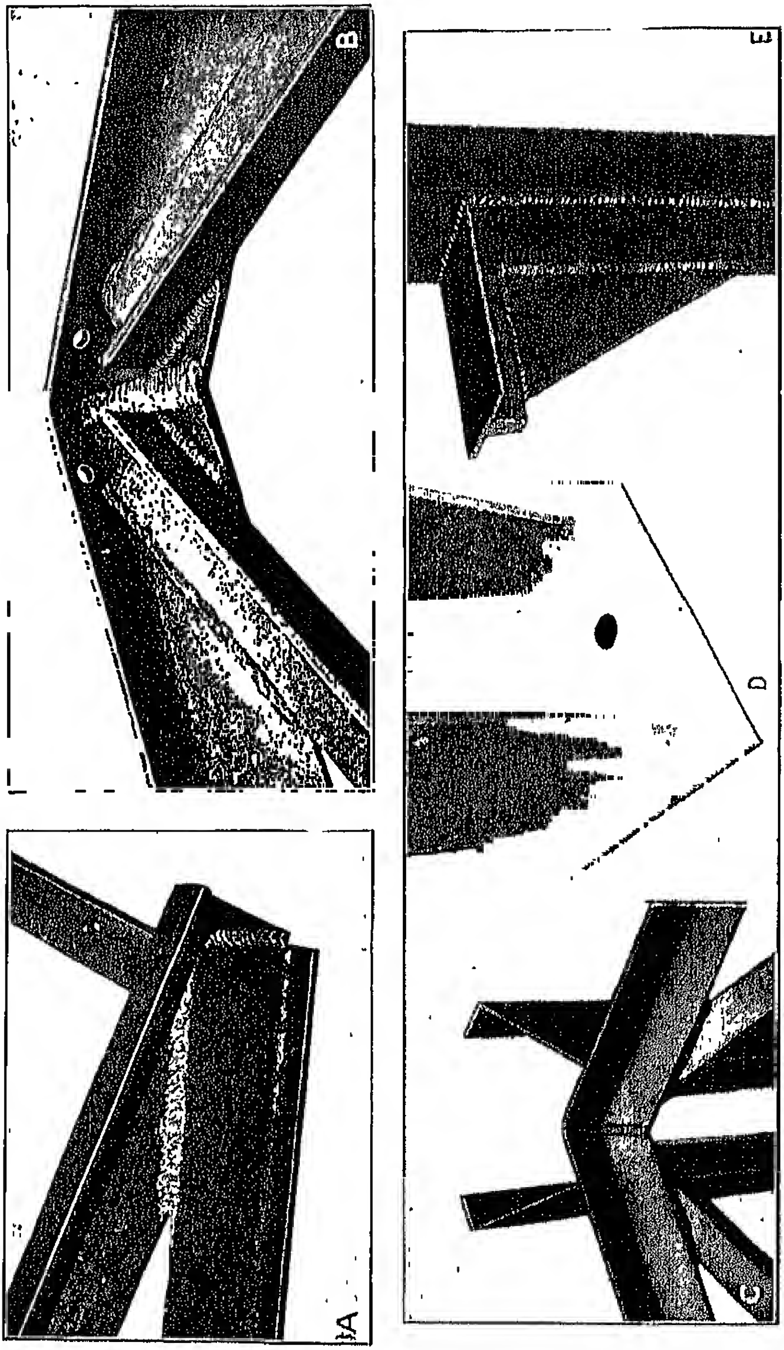


FIG. 148.—Some Details of All-welded Mill Building. *A*, Heel Joint of 40-ft. Truss. *B* and *C*, Front and Back Sides of Peak and Joint Truss. *D*, Column Base. *E*, Crane Bracket. Parts of Bracket were First Welded Together, and then Unit was Welded to the Column.

change during 48 hours, and upon removal of the load at the end of that period a set of less than 0.01 ft. was measured.

Speed of Arc Welding.—In a paper read before the American Institute of Electrical Engineers, New York, Feb. 20, 1919, H. M. Hobart says:

All sorts of values are given for the speed, in feet per hour, with which various types of joints can be welded. Operators making equally good welds have widely varying degrees of proficiency as regards speed. Any quantitative statement must consequently be of so guarded a character as to be of relatively small use. In general, and within reasonable limits, the speed of welding will increase considerably when larger currents are employed. It appears reasonable to estimate that this increase in speed will probably be about 25 to 35 per cent for high values of current. This increase is not directly proportional to the current employed because a greater proportion of time is taken to insert new electrodes and the operator is working under more strenuous conditions. Incidentally, the operator who employs the larger current will not only weld quicker but the weld will have also better strength and ductility.

On this point Mr. Wagner writes as follows:

I would not say that speed in arc welding was proportional to the current used. Up to a certain point ductility and strength improve with increased current, but when these conditions are met, we do not obtain the best speed due to increased heating zone and size of weld puddle. Speed may fall off when current is carried beyond certain points.

In a research made by William Spraragen for the Welding Research Sub-Committee on several tons of half-inch-thick ship plate, the average rate of welding was only two feet per hour. Highly skilled welders were employed, but they were required to do the best possible work, and the kinds of joints and the particular matters under comparison were very varied and often novel.

However, in the researches carried on by Mr. Spraragen it was found that about 1.9 lb. of metal was deposited per hour using a $^5/_{32}$-in. bare electrode and with the plates in a flat position. The amount of electrodes used up was about 2.7 lb. per hour, of which approximately 16.5 per cent was wasted as short ends and 13 per cent burnt or vaporized, the remainder being deposited at the speed of 1.9 lb. per hour mentioned above.

For a 12-ft.-cube tank of ½-in. thick steel welded at Pittsfield, the speed of welding was 3 ft. per hour. The weight of the steel in this tank was 16,000 lb. and the weight of electrode used up was 334 lb. of which 299 lb. was deposited in the welds. The total welding time was 165 hours corresponding to using up electrodes at the rate of just 2 lb. per hour. The total length of weld was 501 ft., the weight of electrode used up per foot of weld thus being 0.60 lb. The design of this tank comprised eighteen different types of welded joint. Several different

operators worked on this job and the average current per operator was 150 amp.

For the British 125-ft.-long Cross-Channel Barge for which the shell plating was composed of $^1/_4$-in. and $^5/_{16}$-in. thick plates, described in H. Jasper Cox's paper read before the Society of Naval Architects on Nov. 15, 1918, and entitled "The Application of Electric Welding to Ship Construction," it is stated that: "After a few initial difficulties had been overcome, an average speed of welding of 7 ft. per hour was maintained including overhead work which averaged from 3 to 6 ft. per hour."

In a report appearing on page 67 of the minutes and records of the Welding Research Sub-Committee for June 28, 1918, O. A. Payne, of the British Admiralty, states: "A good welder could weld on about one pound of metal in one hour with the No. 10 Quasi-Arc electrode, using direct current at 100 volts. An electrode containing about 1½ oz. of metal is used up in about 3 minutes, but this rate cannot be kept up continuously."

The makers of the Quasi-Arc electrode publish the following data for the speed of arc welding in flat position with butt joints, a 60-deg. angle and a free distance of ⅛-in.

Thickness of Plates	Speed in Feet per Hour
⅛ in.	30
¼ in.	18
½ in.	6
1 in.	1.3

I cannot, however, reconcile the high speed of welding ½-in. plate published in this report as 6 ft. per hour, with the report given above by the British Admiralty that a good welder deposits 1 lb. of metal per hour with the Quasi-Arc electrode. If the rate given by the manufacturer is correct, it would mean that about four pounds of metal were deposited per hour. On this basis the rate must have been computed on the time taken to melt a single electrode and not the rate at which a welder could operate continuously, allowing for his endurance and for the time taken to insert fresh electrodes in the electrode holder and the time taken for cleaning the surface of each layer before commencing the next layer. From his observations I am of the opinion that a representative rate for a good welder lies about midway between these values given respectively by Mr. Payne, and by the makers of the Quasi-Arc electrode, say for ½-in. plates some 2 lb. per hour. This, it will be observed, agrees with Mr. Spraragen's experience in welding up some 6 tons of ½-in. ship plate with a dozen or more varieties of butt joint and Mr. Wagner's results with an 8-ton tank. Even this rate of 2 lb. per hour is only the actual time of the welding operator after his plates are clamped in position. This preliminary work and the preparation of the edges which is quite an undertaking, and requires other kinds of artisans, accounts for a large amount of time and should not be under-estimated.

The practice heretofore customary of stating the speed of welding in

feet per hour has led to endless confusion as it depends on type of joint, height of weld and various details. A much better basis is to express the speed of welding in pounds of metal deposited per hour. Data for the pounds of metal deposited per hour are gradually becoming quite definite. The pounds of metal per foot of weld required to be deposited can be readily calculated from the drawings or specifications. With the further available knowledge of the average waste in electrode ends and from other causes, the required amount of the electrode material for a given job can be estimated.

Suitable Current for Given Cases.—For a given type of weld, for example, a double V-weld in a ½-in. thick ship plate, it was found that in the summer of 1918, while some operators employed as low as 100 amp., others worked with over 150 amp. Some, in making such a weld, employed electrodes of only ⅛-in. diameter and others preferred electrodes of twice as great cross-section. For the particular size and design of weld above mentioned, the Welding Research Sub-Committee had welds made with 200 to 300 amp. The conclusion appears justified that the preferable current for such a weld is at least 200 amp. If the weld of the ½-in.-thick plate is of the double-bevel type, some 50 amp. less current should be used for the bottom layer than is used for the second layer, if two layers are used. For ¾-in.-thick plates, the most suitable welding current is some 300 amp. This is of the order of twice the current heretofore usually employed for such a weld.

Mr. Wagner writes:

We have made a number of tests to determine the effect of varying current on the strength of the weld. Tests were made on a ½-in. plate with current values as follows: 80, 125, 150, 180, 220, 275 and 300 amp. These tests show improvement in the tensile strength and bending qualities of welds as the current increases. The speed of welding increases up to a certain point and then decreases.

Effect on Arc Welding of Voltage Employed.—We have made a number of tests to determine the influence of variable voltages on the strength and character of electric welds. The experiments were made welding ½-in. plate with 150 amp. held constant and voltage varying as follows: 40, 75, 100, 125, 150, 200 and 225 volts. This test demonstrates that there is no material difference in the tensile strength, bending qualities or the appearance of the welded-in material. There is this advantage, however, in the higher voltage, that variations in the strength of the arc do not materially affect the value of the current. A curve-drawing ammeter was installed on the welding circuit which showed variations in current at 75 volts, but at 150 volts the current curve was practically a straight line.

Preferable Size of Electrode.—On certain railways, a single diameter of electrode is employed independently of the size or shape of the plates or parts being welded. The experience of other people leads them to make use of several different sizes of electrodes according to the size of the job and the type of joint. Present British practice appears to be to use

such a size of electrode as to have a current density of some 4,000 to 6,000 amp. per square inch. The investigations of the Welding Research Sub-Committee indicate that at least 10,000 to 12,000 amp. per square inch is suitable for electrodes of $^1/_8$-in. and $^5/_{32}$-in. diameter and well up toward 10,000 amp. per square inch for electrodes of $^3/_{16}$-in. and $^3/_4$-in. diameter.

CHAPTER IX

PHYSICAL PROPERTIES OF ARC-FUSED STEEL

The work of the Bureau of Standards in investigating the physical properties of arc-fused steel, was described in Chemical and Metallurgical Engineering, by Henry S. Rowdon, Edward Groesbeck and Louis Jordan. This was by special permission of Director Stratton. The article was substantially as follows:

During the year 1918 at the request of and with the co-operation of the welding research sub-committee of the Emergency Fleet Corporation an extensive program was outlined by the Bureau of Standards for the study of arc-welding. Due to changed conditions, however, at the close of the year 1918, the original program was modified and shortened very considerably. In drawing up the modified program, it was decided to make the study of the characteristic properties of the fused-in metal the primary object of the investigation, the study of the merits of the different types of electrodes being a secondary one. Since the metal of any weld produced by the electric-arc fusion method is essentially a casting, as there is no refinement possible as in some of the other methods, it is apparent that the efficiency of the weld is dependent upon the properties of this arc-fused metal. Hence a knowledge of its properties is of fundamental importance in the study of electric-arc welds.

Preliminary Examinations of Electric-Arc Welds.—Numerous articles have appeared in technical literature bearing on the subject of electric-arc welding. Most of these, however, are devoted to the technique and comparative merits of the method, manipulations, equipment, etc., rather than to the study of the characteristics of the metal of the weld itself. The information on this phrase of the subject is rather meager.

A considerable number of examinations were made of welds prepared by means of the electric-arc process and representative of different conditions of welding.

Most of these were of a general miscellaneous nature and the results do not warrant including a description of the different specimens here. One series of particular interest, however, may well be referred to in detail. As part of this study the welding research sub-committee submitted to the Bureau of Standards a number of welds of ship-plate representative of English practice for examination, some of which were considered as very superior examples of welding as well as others of a decidedly inferior grade. In Tables VII and VIII are given the results obtained by the mechanical tests made upon these specimens. The welding was done by skilled operators by means of special brands of electrodes (welding pencils), the trade names of which, however, have been omitted from the tables. The specimens were examined microscopically very carefully, in addition to the mechanical tests made. The results are not included, however, as the structural features of the material did not differ from those to be discussed in another chapter. The results of the mechanical tests given are of value in that they are indicative of the average mechanical properties which should be expected in electric-arc welds of satisfactory grade for the shape and size of those examined.

Method of Building Specimens.—The specimens required for the study of the mechanical properties of the arc-fused metal were prepared for the most part at the Bureau of Standards, direct current being used in the operation. The apparatus used is shown diagrammatically in Fig. 149. By means of the adjustable water rheostat the current could be increased progressively from 110 to 300 amp. By the use of automatic recording instruments the voltage and current were measured and records were taken at intervals during the preparation of a specimen. The values of current given in the tables are those which were desired and were aimed at. The average deviation from this value as recorded by the curves was approximately 5 amp. The value of the current at the instant "the arc was struck" was of course many times the normal working value used during the fusion.

Since the investigation was concerned primarily with the properties of the arc-fused metal, regular welds were not made. Instead the metal was deposited in a block large enough to

Table VII—Mechanical Properties of Twelve Good Welds *

No.	Average Voltage	Average Amperage	Type of Weld†	Thickness of Plate In.	Ult. Str. Tension, Lb./Sq.In.	Elong., Per Cent		Fracture
1.	d.c. 60	120	Vertical	[illegible]	51,450	7 in 8 in.		In weld; fine crystalline, some holes
2.	d.c. 60	120	Vertical	[illegible]	53,200	11 in 8 in.		In weld, fine crystalline, some holes
3.	a.c. 75	110	Flat	[illegible]	57,430	12 in 8 in.		Outside weld, few holes
4.	a.c. 75	110	Flat	[illegible]	54,210	14 in 8 in.		Outside weld, few holes
5.	d.c. 110	70	Flat	[illegible]	60,610	5 5 in 6 in.		Outside weld, few holes
6.	d.c. 110	125	Flat	[illegible]	59,000	6 in 6 in.		In weld, crystalline, fine to coarse, few holes
7.	d.c. 110	150	Flat	[illegible]	52,570	6 in 6 in.		In weld, very fine crystalline, few holes
8.	d.c. 110	100	Overhead	[illegible]	59,470	4 in 6 in.		In weld, fine crystalline, many holes
9.	d.c. 110	120	Flat	[illegible]	55,460	6 in 6 in.		In weld, crystalline, fine to coarse, few holes
10.	d.c. 110	120	Vertical	[illegible]	49,030	3 7 in 6 in.		In weld, coarse crystalline, few holes
					Cold Bend‡			
					Load at Yield (Lb.)	Load at Break (Lb.)	Angle of Bend, Deg	
11.	d.c. 110	70	Flat	[illegible]	850	1,010	105	
12.	d.c. 110	150	Flat	[illegible]	13,530	17,450	20	In weld; fine crystalline, few holes

* All the welds were made in steel plate of the thickness shown. Electrodes of the covered type were used, the welds were of 60 deg. V type, except the overhead welds in which a 90 deg. V was used.
† Refers to the position of the plates which were being welded together.
‡ The bend tests were made with the apex of V in tension with a 7-in. span over a pin of 2-in. radius except the [illegible]-in. plate for which a pin of 1-in. radius was used.

Table VIII—Mechanical Properties of Twelve Inferior Welds*

No.	Average Voltage	Average Amperage	Type of Weld*	Thickness of Plate, In.	Ult. Str. Tension, Lb./Sq.In.	Elong., Per Cent		Fracture
13	d.c. 110	120	Flat	[illegible]	32,460	Nil		In weld: fine crystalline, many holes
14	d.c. 95	105	Vertical	[illegible]	19,890	Nil		In weld spongy metal, poor junction with metal of plate
15	d.c. 95	105	Flat	[illegible]	31,700	Nil		In weld spongy metal, poor junction with metal of plate
16.	d.c. 60	120	Flat	[illegible]	37,290	2 in 6 in.		In weld, very fine grained with many holes
17.	d.c. 60	110	Vertical	[illegible]	38,820	2 in 6 in.		In weld, coarse, crystalline, many holes
18.	a.c. 75	110	Vertical	[illegible]	31,360	Nil		In weld fine to coarse crystalline, many holes
19.	a.c. 75	110	Vertical	[illegible]	27,090	1 4 in 8 in.		In weld coarse crystalline, many holes
20.	d.c. 110	120	Vertical	[illegible]	39,400	3 5 in 6 in.		In weld: very fine grained with crystalline areas many holes
21	d.c. 110	120	Flat	[illegible]	34,650	Nil		In weld very fine grained, very many holes
22	d.c. 110	120	Flat	[illegible]	35,120	Nil		In weld very fine to coarse crystalline, many holes
					Cold Bend Test*			
					Load at Yield	Load at Break	Angle of Bend, Deg	
23	d.c. 95	105	Flat	[illegible]	4,930	4,930	Nil	In weld, very many laps and holes
24	d.c. 95	105	Vertical	[illegible]	4,120	4,610	[illegible]	In weld very many laps and holes

* See corresponding notes, Table VII.

permit a tension specimen (0.505 in. diameter, 2 in. gage length) to be machined out of it. Although the opinion is held by some welders that the properties of the metal of an arc-weld are affected materially by the adjacent metal by reason of the interpenetration of the two, it was decided that the change of properties of the added metal induced by the fusion alone was of fundamental importance and should form the basis of any study of arc-welding. The method adopted also permitted the use of larger specimens with much less machining

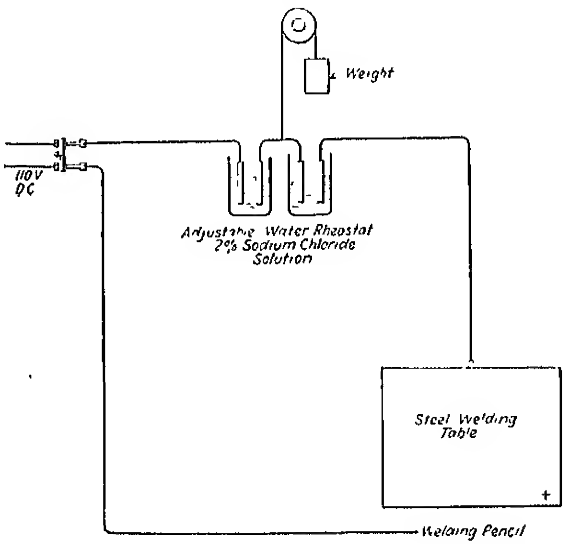


FIG. 149.—Arrangement of Apparatus for Welding.

than would have been possible had the metal been deposited in the usual form of a weld.

In the first few specimens prepared (ten in number) the metal was deposited by a series of "beadings" inside a 1½-in. angle iron. The tension specimens cut from the deposited metal were found to be very inferior and entirely unsuitable for the study. This was largely on account of the excessive overheating which occurred as well as the fact that a relatively "long arc" was necessary for the fusion in this form. Because of the very evident inferiority of these specimens, the results of the mechanical tests made are not given in the tables. The method of deposition of the metal was then changed to

that shown in Fig. 150. This method also had the advantage in that the amount of necessary machining for shaping the specimens for test was materially reduced. The block of arc-

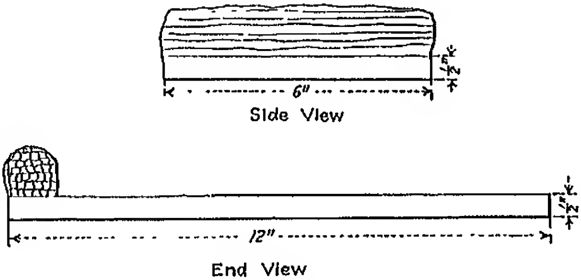


FIG. 150.—Method of Formation of the Blocks of Arc-Fused Metal.

fused metal was built up on the end of a section of ½-in. plate of mild steel (ship plate) as shown. When a block of sufficient size had been formed, it, together with the portion

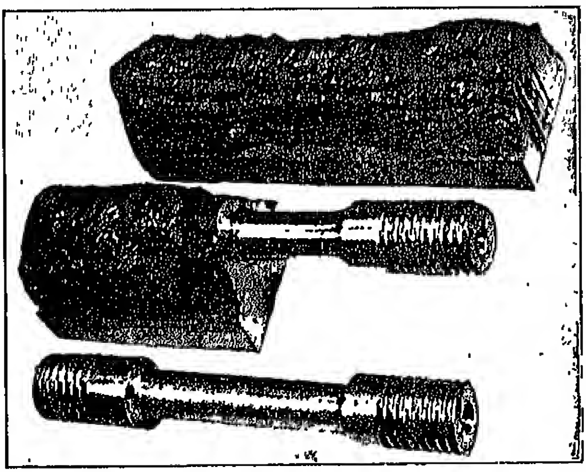


FIG. 151.—Block of Arc-Fused Metal with Tension Specimen Cut from It. Approximately Half Natural Size.

of the steel plate immediately beneath, was sawed off from the remainder of the steel plate. The tension specimen was turned entirely out of the arc-fused metal. No difficulty whatever was experienced in machining the specimens. Fig. 151

shows the general appearance of the block of fused metal as well as the tension specimen turned out of it.

In general in forming the blocks, the fused metal was deposited as a series of "beads" so arranged that they were parallel to the axis of the tension specimen which was cut later from the block. In two cases, for purposes of comparison, the metal was deposited in "beads" at right angles to the length of the specimen. In all the specimens, after the deposition of each layer, the surface was very carefully and vigorously brushed with a stiff wire brush to remove the layer of oxide and slag which formed during the fusion. There was found to be but little need to use the chisel for removing this layer.

Two types of electrodes were used as material to be fused. These differed considerably in composition as shown in Table IX, and were chosen as representative of a "pure" iron and a low-carbon steel. The two types will be referred to as "A" and "B" respectively in the tables. They were obtained in the following sizes: $^1/_8$, $^5/_{32}$, $^3/_{16}$ and $^1/_4$ in. ("A" electrode $^5/_{16}$ in.). It was planned to use the different sizes with the following currents: $^1/_4$ in.—75, 110 and 145 amp.; $^5/_{32}$ in.—145, 185 and 225 amp.; $^3/_{16}$ in.—185, 225 and 260 amp.; $^1/_4$ in. ($^5/_{16}$ in.)—300 amp. The electrodes were used both in the bare condition and after being slightly coated with an oxidizing and refractory mixture. For coating, a "paste" of the following composition was used: 15 g. graphite, 7.5 g. magnesium, 4 g. aluminium, 65 g. magnesium oxide, 60 g. calcium oxide. To this mixture was added 120 c.c. of sodium silicate (40 deg. Bé.) and 150 c.c. of water. The electrodes were painted on one side only with the paste. The quantity given above was found to be sufficient for coating 500 electrodes. The purpose of the coating was to prevent excessive oxidation of the metal of the electrode during fusion and to form also a thin protective coating of slag upon the fused metal.

Tension specimens only were prepared from the arc-fused metal. It is quite generally recognized that the tension test falls very short in completely defining the mechanical properties of any metal; it is believed, however, that the behavior of this material when stressed in tension is so characteristic that its general behavior under other conditions of stress,

TABLE IX—COMPOSITION OF ELECTRODES BEFORE AND AFTER FUSION *

Electrode		Carbon		Silicon		Manganese		Phosphorus		Sulphur		Copper†		Nitrogen§		
Type	Size, In	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
A	1/8	0.058	0.046 0.031‡	0.33	0.007 0.007‡	0.042	tr tr	0.002	0.005 0.005‡	0.057	0.036 0.033‡	.....	.....	0.0030	0.156 0.127	0.149‡ 0.140‡
A	5/32	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.0035	0.140 0.123 0.124	0.121‡ 0.119‡ 0.113‡
A	3/16	0.022	0.010 0.010‡ 0.033	0.16	0.012 0.014‡ 0.006	0.038	tr tr‡ 0.069	0.002	0.003 0.002‡ 0.012	0.040	0.033 0.035‡ 0.043	.....	0.058	0.0040	0.126 0.131 0.133	0.127‡ 0.131‡ 0.134‡
A	3/32	.....	0.050	.....	0.11	.....	0.014	.....	0.011	.....	0.026	.....	0.063	0.0037	0.117	0.111‡
B	1/8	0.15	0.027 0.024‡	0.06	0.008 0.010‡	0.47	tr tr‡	0.018	0.002 0.004‡	0.021	0.035 0.035‡	.....	.....	0.0032	0.152 0.132	0.141‡ 0.135‡
B	5/32	0.15	.....	0.001	.....	0.46	.....	0.014	.....	0.017	.....	.....	.....	0.0035	0.124 0.121 0.117	0.122‡ 0.132‡¶ 0.123‡
B	3/32	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.0022 0.0025	0.119 0.111 0.112	0.106‡ 0.108‡ 0.094‡
B	1/8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.0014 0.0022		
C	..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		0.133 0.098	

* The electrodes which furnished the specimens used for analysis after fusion were not the identical ones used before fusion but were the same stock
† Determinations for copper were not carried out upon the unfused electrodes.
‡ Results were obtained from the fusion of coated electrodes
§ Each of the results reported in the "after" fusion columns is the average of two determinations, excepting as noted below, made on one separate specimen. Credit is due to J. R. Cain, chemist, Bureau of Standards for this method, details to be published later
¶ Average of nine determinations.

particularly when subjected to the so-called dynamic tests—i.e., vibration and shock—can be safely predicted from the results obtained. In order to supplement the specimens made at the Bureau a series of six were also prepared by one of the large manufacturers of equipment for electric welding to be included in the investigation. These are designated as "C" in the tables.

In Table IX it will be noted that the general effect of the fusion is to render the two materials used for welding pencils more nearly the same in composition. The loss of carbon and of silicon is very marked in each case where these elements exist in considerable amounts. A similar tendency may be noted for manganese. The coating with which the electrodes were covered appears to have but little influence, if any, in preventing the oxidation of the carbon and other elements.

Table X—Relation Between Nitrogen-content and Current Density *

Size of Elec-trode, In	Amperes (Approx)	Current Density	Nitrogen Content (Per Cent †) "A" Spec	"B" Spec.	"C" Spec.	Average
$\frac{1}{8}$	110	9,000	0 156 0 149§	0 152 0 141§	. .	0 138
$\frac{1}{8}$	145	11,800	0 127 0 140§	0 132 0 135§	. .	0 126
$\frac{5}{32}$	145	7,600	0 140 0 121§	0 124 0 122§	. ..	0 127
$\frac{5}{32}$	185	9,650	0 123 0 119§	0 121 0 163§ 0 132‡	.	0 131
$\frac{5}{32}$	225	11,700	0 124 0 113§	0 117 0 123§	. .	‡
$\frac{5}{32}$	175	9,100		. . .	0 133 0 098	b
$\frac{3}{16}$	185	6,700	0 126 0 127§	0 119 0 106§	. ..	0 120
$\frac{3}{16}$	225	8,150	0 131 0 131§	0 111 0 108§	. ..	0 120
$\frac{3}{16}$	260	9,400	0 133 0 134§	0.112 0 094	.	0 118
$\frac{3}{16}$	300	3,900	0 117 0 111§	.. .	.	0 114

* Credit due J. R. Cain.
† Average of two determinations.
‡ Included in average for C-D 11,800.
§ Coated electrodes.
b Included in average for C-D 9,000.
a Average of 9 determinations

The most noticeable change in composition is the increase in the nitrogen content of the metal. In general the increase was rather uniform for all specimens. In Table X are summarized the results of the nitrogen determinations together

TABLE XI—TENSILE PROPERTIES OF ELECTRODES

Electrode	Size, In.	Ult. Strength, Lb. Sq In.	Propor. Limit, Lb. Sq. In	Elong in 2 In Per Cent	Reduct. Area, Per Cent
A	3/32	65,800	39,000	16 5	69 2
A	1/8	62,100	48,000	9 0	69 3
A	5/32	60,100	34,500	14 0	66 4
A	3/16	57,300	.	15 5	67 6
B	3/32	88,600	67,000	4 5	51 3
B	3/16	84,700	58,500	7 0	59 8
B	1/4	66,300	37,500	15 0	61 4
B	1/4	67,900		15 5	62 4

with the corresponding current density used for the fusion of the metal. In Fig. 152 the average nitrogen contents found for the different conditions of fusion are given and plotted against the corresponding current density. Though no definite conclusion seems to be warranted, it may be said that, in

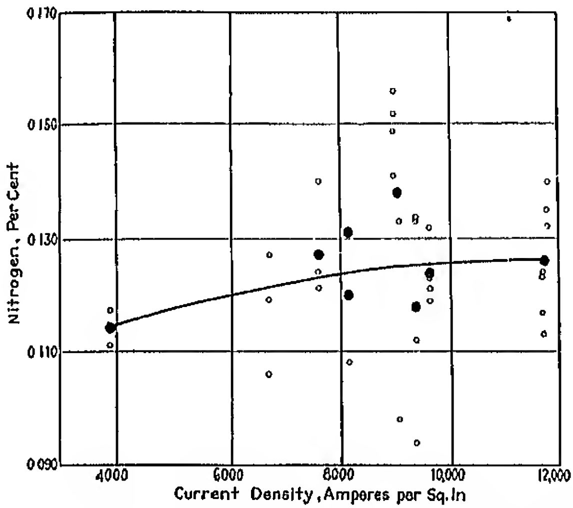


FIG. 152.—Relation of Current Density to Nitrogen Content in Arc-Fused Iron.

Black dots represent averages.

general, the percentage of nitrogen taken up by the fused iron increases somewhat as the current density increases. With the lowest current densities used the amount of nitrogen was found to decrease appreciably.

Mechanical Properties of the Arc-Fused Metal.—The mechanical properties of the two types of electrodes used as determined by the tension test are summarized in Table XI.

TABLE XII—TENSILE PROPERTIES AND HARDNESS OF FIFTY SPECIMENS OF WELD-METAL AT THE BUREAU. (0.505-IN. DIAM. STANDARD TENSION BAR USED)

Sample No.	Size Electrode, In.	Amp., D. C	Tensile Properties: Ult Strength	Tensile Properties: Yield Pt.	Tensile Properties: Proportional Limit	Elong. in 2 In., per Cent	Reduc Area, per Cent	Brinell Hardness
Bare Electrodes								
A2	1/8	110	49,850	36,600	25,000	6.0	6.5	108
A3	1/8	145	51,950	36,250	30,000	8.0	13.0	114
A7	5/32	145	47,550	..		6.0	7.4	108
A8	5/32	185	48,100	. .	. .	8.0	8.7	104
A9	5/32	225	45,500			8.0	9.6	101
A4	3/16	185	50,600	33,750	29,500	5.5	13.5	105
A5	3/16	225	49,150	36,250	22,000	7.0	10.0	102
A6	3/16	260	50,950	33,750	28,800	10.5	12.0	107
A10	3/16	300	46,670	. ..		12.0	11.9	104
Covered Electrodes								
AD2	1/8	110	51,250	35,000	25,600	9.5	11.0	103
AD2-D	1/8	110	43,000		23,000	5.0	9.0	
AD3	1/8	145	51,100	33,750	25,000	8.5	10.5	110
AD3-D	1/8	145	46,250	.	24,250	7.0	12.0	
AD7	5/32	145	41,750	...		6.0	6.6	99
AD7-D	5/32	145	46,950	. .	25,500	8.0	9.4	
AD8	5/32	185	44,620	. . .		6.5	5.8	103
AD8-D	5/32	185	43,600	.	23,250	6.5	9.0	
AD9	5/32	225	46,900	. .		9.5	10.1	96
AD9-D	5/32	225	41,550		25,500	5.0	6.5	
AD4	3/16	185	51,200	35,000	30,000	10.5	10.5	101
AD4-D	3/16	185	45,700		25,500	8.5	11.5	
AD5	3/16	225	48,600	35,000	30,000	7.0	10.0	96
AD5-D	3/16	225	46,250	.	23,750	11.5	12.0	
AD6	3/16	260	47,500	34,500	31,500	9.0	9.0	97
AD6-D	3/16	260	50,700		...	8.0	2.8	105
AD10	3/16	300	45,900	...	.....	8.5	11.5	98
Bare Electrodes								
B2	1/8	110	52,650	37,000	27,000	7.5	7.5	114
B3	1/8	145	54,500	36,000	27,000	12.5	12.0	106
B4	5/32	145	46,450	33,500	26,000	5.0	7.0	102
B5	5/32	185	49,600	34,250	27,000	7.5	9.0	108
B6	5/32	225	49,500	30,500	28,000	9.0	5	110
B7	3/16	185	47,550		28,500	7.5	11.5	95
B8	3/16	225	42,900	.	18,750	7.5	16.2	101
B9	3/16	260	47,500		21,500	12.0	13.5	102
Covered Electrodes								
BD2	1/8	110	49,050	33,750	27,500	9.0	12.0	100
BD2-D	1/8	110	44,400		20,000	6.5	9.4	
BD3	1/8	145	52,100	34,300	30,500	12.5	16.0	116
BD3-D	1/8	145	50,850		23,500	13.0	17.5	
BD4	5/32	145	48,130	31,000	30,500	8.0	10.0	101
BD4-D	5/32	145	41,750		21,000	6.0	9.5	
BD5	5/32	185	49,086	31,730	29,000	12.5	13.0	97
BD5-D	5/32	185	47,100		22,500	11.0	12.5	
BD6	5/32	225	45,500	30,500	25,000	8.5	10.5	95
BD7	3/16	185	49,950	..	24,500	11.5	21.5	98
BD7-D	3/16	185	51,150	, .	23,750	14.5	19.5	
BD8	3/16	225	41,500	...	17,850	6.0	12.7	99
BD8-D(?)	3/16(?)	225(?)	48,750	, .	21,250	12.5	16.0	
BD9	3/16	260	46,350	....,	24,000	10.0	15.0	99
Bare Electrodes								
C1	5/32	175	48,650	32,650	23,000	12.0	19.1	. .
C2	5/32	175	45,200	32,400	23,000	7.5	16.6	. .
C3	5/32	175	49,720	32,650	25,000	9.0	13.6	
C4	5/32	175	54,500	32,500	25,000	11.0	17.5	118
C5	5/32	175	50,900	32,500	24,000	15.0	23.0	109
C6	5/32	175	50,500	33,500	23,000	12.0	16.0	

TABLE XIII—TENSILE PROPERTIES AND HARDNESS OF FIFTY SPECIMENS OF WELD-METAL PREPARED BY THE BUREAU—ARRANGED IN ORDER OF AMPERAGE USED

Amperage	Tensile Properties																			
	Ultimate Strength Lb. Sq.In.				Yield Point Lb Sq In				Elongation in 2 In per Cent				Reduction of Area per Cent				Brinell Hardness			
	A*		B*		A		B		A		B		A		B		A		B	
Used Amps.†	Bare	Covered	Bare	Covered	Bare	Covered	Bare	Covered	Bare	Covered	Bare	Covered	Bare	Covered	Bare	Covered	Bare Brin.	Covered Brin.	Bare Brin.	Covered Brin.
110	49,850	51,250 43,000‡	52,650	49,050 44,000‡	36,600	35,000 ‡	37,000	33 750 ‡	6	9 5 5 0‡	7 5	9 0 6 5‡	6.5	11 0 9 0‡	7 5	12 0 9 4‡	108	103	114	100
145	51,950	51,000 46,250‡	54,500	52,100 50 850‡	36,250 ..	33,750 ..‡	36,000	34,300 ‡	6.0	8 5 7 0‡	12 5	12 5 13.0‡	13 0	10 5 12 0‡	12 0	16 0 17 5‡	114	110 ..	106	116
	47,550	41,750 46,950‡	46,450	48,130 41,750‡	. ....	... . .	33,500	31,000 ‡	6 0	6 0 8 0	5 0	8 0 6 0‡	7.4	6 6 9 4‡	7 0	10 0 9 5‡	106	99	102	101
185	48,100	44,620 43 600‡	49,600	49,086 47,100‡	.... . .	.	34,250	31,730 ..	8 0	6 5 6 5‡	7 5	12 5 11 0‡	8 7	5 8 9 0‡	9 0	13 0 12 5‡	104	103	108	97
	50,600	51,200 45,700‡	47,550	49,950 51,150‡	33,750	35,000 .. ‡	..	. ‡	5 5	10 5 8 5‡	7.5	11 5 14 5‡	13 5	10 5 11 5‡	11 5	21 5 19 5‡	105	101	95	98
225	45,500	45,900 41,550‡	49,500	45,500	.	‡	30,500	30,500	8 0	9 5 5 0‡	9.0	8 5	9 6	10 1 6 5‡	7 5	10 5	101	96	110	95
	49,150	43 600 44,250‡	42,900	41,500	36,250	35,000 ‡	. .	.. . . .	7 0	7.0 11 5‡	7 5	6 0	10 0	10 0 12 0‡	16 2	12 7	102	96	101	99
260	50,950	47,500 50,700‡	47,500	46,350	33,750	34,500 ... ‡	..	. .	10 5	9 0 8 0‡	12 0	10 0	12 0	9 0 2 8‡	13 5	15 0	107	97	102	99
300	46,670	45,900							12 0	8 5	...		11 9	11 5			104			
Average	48,900	46,600	48,800	47,450	35,300	34,650	34,250	32,250	7.9	8 5	8 5	9.9	10 3	9.2	10 5	13 8	106	100	105	101
	Av. 47,400		Av. 47,980		Av 35,000		Av. 33,250		Av. 7 9		Av. 9 0		Av 9 6		Av. 12.5		Av. 103		Av. 103	

* A and B refer to the two types of electrodes used (Table III)

† Size of electrode used: ⅛ in. diam. = 110 amps. and 145 (1) amps $\frac{5}{32}$ in. diam. — 145 (2) amp., 185 (1) amp and 225 (1) amp. $\frac{3}{16}$ in diam — 185 (2) amp., 225 (2) amp. 260 amp. ¼ in. diam.—300 amp.

‡ Duplicate specimen.

In Table XII are given the results of the mechanical tests made upon the tension specimens which were turned out of the blocks of metal resulting from the fusion of the electrodes.

The specimens listed, C_1, $C_2 \ldots C_6$ are the six which were prepared outside the Bureau and submitted for purposes of comparison. It was stated that they were prepared from bare electrodes $^5/_{32}$ in. diameter of type "B," containing 0.17 per cent carbon and 0.5 per cent manganese.

As an aid for more readily comparing the mechanical properties of the two types of arc-fused metal "A" and "B," the results have been grouped as given in Table XIII.

The characteristic appearance of specimens after testing, illustrating their behavior when stressed in tension till rupture occurs is shown in Fig. 153. These represent two views of the face of the fracture, one in which the line of vision is perpendicular to the face, the other at an angle of 45 deg., together with a side view of the cylindrical surface of the specimen. The features shown are characteristic of all the specimens tested, though in some they were much more pronounced than those shown. The fracture of the specimen in all cases reveals interior flaws. In some of the specimens, however, these are microscopic and of the character to be discussed in a subsequent chapter on Metallography. Although many of the specimens (from the results of Table XII) appear to have a considerable elongation, it is seen from Fig. 153 that the measured elongation does not truly represent a property of the metal itself. It is due rather to interior defects which indicate lack of perfect union of succeeding additions of metal during the process of fusion. The surface markings of the specimen after stressing to rupture are very similar to those seen in the familiar "flaky steel."

Resulting Physical Properties Depend Essentially on Soundness.—It appears from the results above that, as far as the mechanical properties are concerned, nothing was gained by coating the electrodes. The results show no decided superiority for either of the two types of electrodes used. This may be expected, however, when one considers that the two are rendered

practically the same in composition during fusion by the burning out of the carbon and other elements.

The results of the tension tests upon the "C" series of

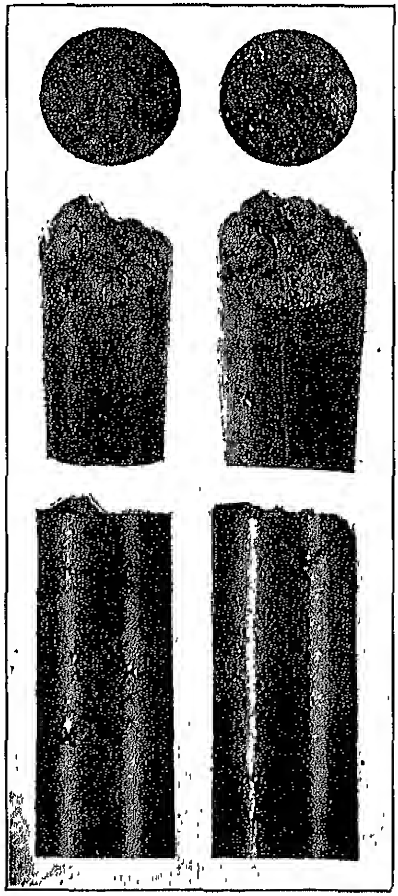


Fig. 153.—Characteristic Appearance of Tension Specimen After Test.

At top, face of fracture, viewed normally. Middle, fractured end of specimen, viewed at an angle of 45 deg. At bottom, cylindrical surface of specimen. Magnification, × 2.

specimens which were made outside of the Bureau and submitted to be included in the investigation, show no marked difference between these samples and those prepared by the Bureau. In all cases the results obtained in the tension test

are determined by the soundness of the metal and do not necessarily indicate the real mechanical properties of the material.

The results of the hardness determinations do not appear to have any particular or unusual significance. The variations are of the same general nature and relative magnitude as the variations observed in the results of the tension test. In general the higher hardness number accompanies the higher tensile values, though this was not invariably so. As previously noted, specimens were prepared for the purpose of showing the relation between the direction in which the stress is applied and the manner of deposition of the metal. The metal was deposited in the form shown in Fig. 151, except that the "beads" extended across the piece rather than lengthwise, hence the "beads" of fused metal were at right angles to the direction in which the tensional stress was applied. The results of the tension tests show that these two specimens (AW_1 and AW_2) were decidedly inferior to those prepared in the other manner as shown in Table XIV.

TABLE XIV.—MECHANICAL PROPERTIES OF ARC-FUSED METAL DEPOSITED AT RIGHT ANGLES TO LENGTH OF SPECIMEN

Specimen	Ult. Strength, Lb. Sq. In.	Proportional Limit, Lb. Sq. In.	Elongation in 2 in. (per Cent)	Red. of Area, per Cent
AW^1	40,450	22,500	6.5	8.5
AW^2	39,500	22,500	4.0	3.0

Macrostructure.—The general condition of the metal resulting from the arc-fusion is shown in Figs. 154 and 155, which show longitudinal median sections of a series of the tension bars adjacent to the fractured end. The metal in all of these specimens was found to contain a considerable number of cavities and oxide inclusions, these are best seen after the surfaces are etched with a 10 per cent aqueous solution of copper-ammonium chloride. In many of the specimens the successive additions of metal are outlined by a series of very fine inclusions (probably oxide) which are revealed by the etching. There appears to be no definite relation between the soundness of the metal and the conditions of deposition—i.e., for the range of current density used—nor does either type

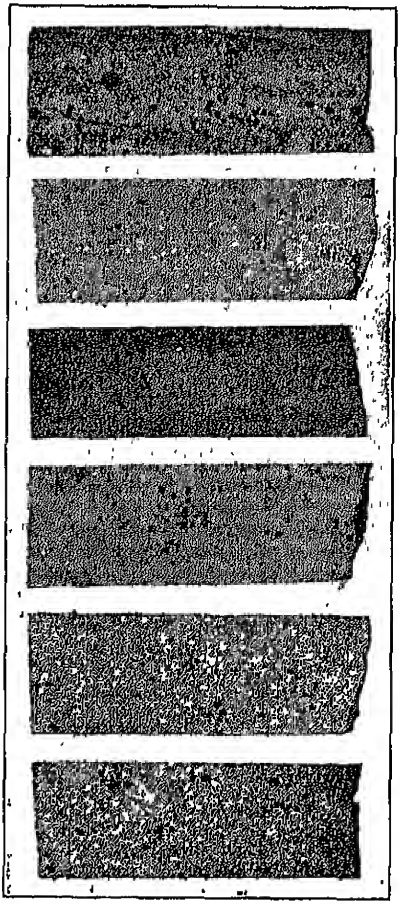


Fig. 154.—Macrostructure of Arc-Fused Metal, Type A.

Medial Longitudinal sections of the tension bars indicated were used (Table XII); etching, 10 per cent aqueous solution of copper-ammonium chloride. Magnification, × 2. From top to bottom in order:

AD6—A electrode; 3/16 in., covered, 260 amp.
A5—A electrode; 3/16 in., bare, 225 amp.
A6—A electrode; 3/16 in., bare, 260 amp.
A8—A electrode; 1/8 in., bare, 145 amp.
A4—A electrode; 3/16 in., bare, 185 amp.
AD2—A electrode; 1/8 in., covered, 110 amp.

of electrode used show any decided superiority over the other with respect to porosity of the resulting fusion. In Fig. 156

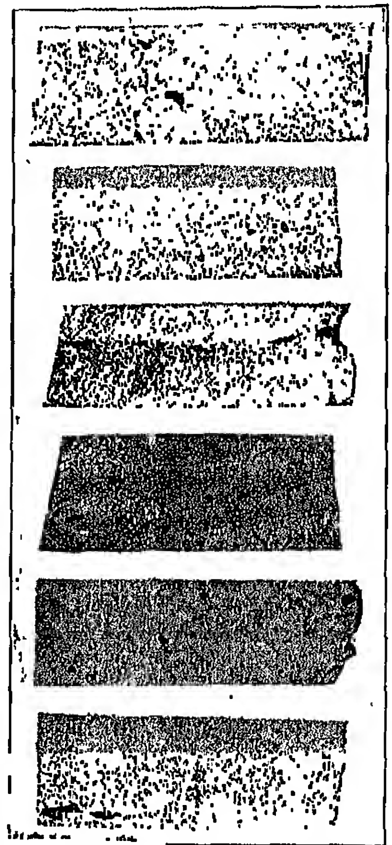


FIG. 155.—Macrostructure of Arc-Fused Metal, Type B.

Medial longitudinal sections of the tension bars indicated were used (Table XII); etching, 10 per cent aqueous solution of copper-ammonium chloride. Magnification, × 2. From top to bottom in order:

B4—B electrode, 5⁄32 in., bare, 145 amp.
B5—B electrode; 5⁄32 in., bare, 185 amp.
B2—B electrode; ⅛ in., bare, 110 amp.
B3—B electrode; ⅛ in., bare, 145 amp.
BD6—B electrode; 5⁄32 in., covered, 225 amp.
BD4—B electrode; 5⁄32 in., covered, 145 amp.

is shown the appearance of a cross-section of one of the blocks of arc-fused metal prepared outside of the Bureau by skilled

welding operators. The condition of this material is quite similar to that prepared by the Bureau.

The microscopic study of the material to be discussed in a subsequent chapter also revealed further evidence of unsoundness in all three types, "A," "B" and "C."

Discussion of Results.—In any consideration of electric-arc welding it should constantly be borne in mind that the weld-

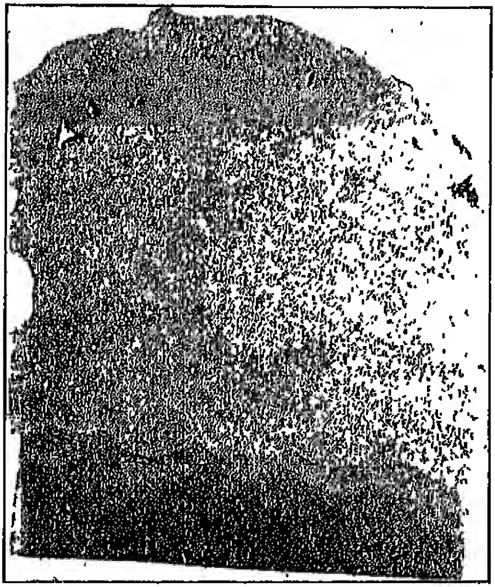


Fig. 156.—Macrostructure of Arc-Fused Metal, Type C.

Specimen C1 (Table XII), cross section of the block of arc-fused metal from which the tension bar was turned; etched with 5 per cent alcoholic solution of picric acid. Magnification, × 1.7.

metal is simply metal which has been melted and has then solidified in situ. The weld is essentially a casting, though the conditions for its production are very different from those ordinarily employed in the making of steel castings. The metal loses many of the properties it possesses when in the wrought form and hence it is not to be expected that a fusion weld made by any process whatever, will have all the properties that metal of the same composition would have when in the forged or rolled condition. A knowledge of the char-

acteristic properties of the arc-fused iron is then of fundamental importance in the study of the electric-arc weld.

The peculiar conditions under which the fusion takes place also render the metal of the weld quite different from similar metal melted and cast in the usual manner. It is seemingly impossible to fuse the metal without serious imperfections. The mechanical properties of the metal are dependent therefore to an astonishing degree upon the skill, care and patience of the welding operator. The very low ductility shown by specimens when stressed in tension is the most striking feature observed in the mechanical properties of the material as revealed by the tension test. As explained above, the measured elongation of the tension specimen does not truly indicate a property of the metal. Due to the unsoundness, already described in the discussion of the structure, the true properties of the metal are not revealed by the tension test to any extent. The test measures, largely for each particular specimen, the adhesion between the successively added layers which value varies considerably in different specimens due to the unsoundness caused by imperfect fusion, oxide and other inclusions, tiny enclosed cavities and similar undesirable features. The elongation measured for any particular specimen is due largely, if not entirely, to the increase of length due to the combined effect of the numerous tiny imperfections which exist throughout the sample.

That the metal is inherently ductile, however, is shown by the behavior upon bending (later to be discussed) in the microstructure of bent specimens. The formation of slip-bands within the ferrite grains to the extent which was observed is evidence of a high degree of ductility. It appears, however, that the grosser imperfections are sufficient to prevent any accurate measurement of the real mechanical properties of the metal from being made. The conclusion appears to be warranted therefore that the changes of composition which the fusion entails, together with the unusual features of microstructure which accompany the composition change are of minor importance in determining the strength, durability and other properties of the arc weld.

In arc-fusion welds in general, the mass of weld-metal is in intimate contact with the parts which are being welded so that

it is claimed by many that because of the diffusion and intermingling of the metal under repair with that of the weld, properties of the latter are considerably improved. The comparison shown in Table XV somewhat supports this claim. The nearest comparison found available with the Bureau's specimen are some of those of the welds designated as the "Wirt-Jones" series reported by H. M. Hobart. These welds were of the 45 deg. double-V type made in ½-in. ship plate; the specimens for test were of uniform cross-section $1 \times \frac{1}{2}$ in., the projecting metal at the joint having been planed off even with the surface of the plates and the test bars were so taken that the weld extended transversely across the specimen near the center of its length. The electrodes used were similar to those designated as type "B" in the Bureau's investigation.

Table XV.—Comparison of Welds with Tests of Arc-fused Metal Prepared Under Similar Conditions.

Bureau of Standards				Wirt-Jones			
Size Electrode, In	D C Amp	Ult. Strength, Lb./Sq.In	Elong Per Cent per 2 In	Size Electrode,* In	D C Amp.	Ult. Strength, Lb./Sq In	Elong Per Cent In 2 In
1/8	110	52,650	7.5	1/8	110	45,800	8.0
1/8†	110	49,050	9.0	1/8	115	58,200	14.0
1/8†	110	44,400	6.5	1/8	115	59,400	13.5
Average		48,700	7.7	1/8	120	53,700	7.0
5/32	145	46,450	5.0	1/8	120	57,600	8.5
5/32	145	48,130	8.0	Average		54,940	10.2
5/32	145	41,750		5/32	150	60,900	8.0
Average		45,440	6.3	3/16	155	62,600	11.5
3/16	185	49,600	7.5	Average		61,750	9.8
3/16	185	49,086	12.5	5/32	175	59,800	9.0
3/16	185	47,100	11.0				
Average		48,395	10.3				

* Electrodes were used in bare condition.
† Electrodes were coated as previously described, those not so designated in this column were used bare

Since the specimens used in work described in the foregoing sections were prepared in a manner quite different from the usual practice of arc-welding, no definite recommendations applicable to the latter can be made. It appears, however, from the results obtained that the two types of electrodes used —i.e., "pure" iron and low-carbon steel—should give very similar results in practical welding. This is due to the changes which occur during the melting so that the resulting fusions are essentially of the same composition. The use of a slight

coating on the electrodes does not appear to be of any material advantage so far as the properties of the resulting fused metal are concerned. Since the program of work as carried out did not include the use of any of the covered electrodes which are highly recommended by many for use in arc welding, particularly so, for "overhead work," no data are available as to the effect of such coatings upon the properties of the metal resulting from fusion. Although all of the specimens used in the examinations were made by the use of direct current, it appears from the results obtained with a considerable number of welds representing the use of both kinds of current, submitted for the preliminary examinations which were made, that the properties of the fused metal are independent of the kind of current and are influenced primarily by the heat of fusion. Any difference in results obtained by welding with alternating current as compared with those obtained with direct current apparently depends upon the relative ease of manipulation during welding rather than to any intrinsic effect of the current upon properties of the metal.

CHAPTER X

METALLOGRAPHY OF ARC-FUSED STEEL

The same authors responsible for the description of the investigations at the Bureau of Standards, given in the previous chapter, also furnished the data given in this chapter:

Fusion welds evidently are fundamentally different from other types of joints in that the metal at the weld is essentially a casting. A preliminary study of a considerable number of specimens welded under different conditions confirmed the impression that the arc-fusion weld has characteristics quite different from other fusion welds.

In the present study, of which both the previous chapter and this one form a part, two types of electrodes, a "pure" iron called "A" and a mild steel called "B," were used, in the bare condition, and also after receiving a slight coating. With these were included a set of similar specimens prepared outside of the Bureau by expert welding operators. During the fusion the composition of the metal of the two types of electrodes is changed considerably by the "burning-out" of the carbon and other elements, the two becoming very much alike in composition. A very considerable increase in the nitrogen content occurs at the same time, as shown by chemical analysis.

The mechanical properties of the arc-fused metal as measured by the tension test are essentially those of an inferior casting. The most striking feature is the low ductility of the metal. All of the specimens showed evidence of unsoundness in their structure, tiny inclosed cavities, oxide inclusions, lack of intimate union, etc. These features of unsoundness are, seemingly, a necessary consequence of the method of fusion as now practiced. They determine almost entirely the mechanical properties of the arc-fused metal. The observed elongation of the specimen under tension is due to the combined action of

the numerous unsound spots rather than to the ductility of the metal. That the metal is inherently ductile, however, will be shown by the changes in the microstructure, produced by cold-bending. By taking extreme precautions during the fusion, a great deal of the unsoundness may be avoided and the mechanical properties of the metal be considerably improved. The specimens described, however, are more representative of actual present practice in welding.

General Features of Microstructure.—For purposes of comparison the microstructure of the electrodes before fusion is shown in (1) and (2), Fig. 157. The "A" electrodes have the appearance of steel of a very low carbon content; in some cases they were in the cold-rolled state; all showed a considerable number of inclusions. The "B" electrodes have the structure of a mild steel and are much freer from inclusions than are those of the other type. It is, undoubtedly true, however, that the condition of the arc-fused metal with respect to the number of inclusions is a result of the fusion rather than of the initial state of the metal.

It is to be expected that the microstructure of the material after fusion will be very considerably changed, since the metal is then essentially the same as a casting. It has some features, however, which are not to be found in steel as ordinarily cast. The general type of microstructure was found to vary in the different specimens and to range from a condition which will be designated as "columnar" to that of a uniform fine equi-axed crystalline arrangement as shown at 3 and 4, Fig. 157A. This observation held true for both types of electrodes, whether bare or covered. In the examination of cross-sections of the blocks of arc-fused metal, it was noticed that the equi-axed type of structure is prevalent throughout the interior of the piece and the columnar is to be found generally nearer the surface—i.e., in the metal deposited last. It may be inferred from this that the metal of the layers which were deposited during the early part of the preparation of the specimen is refined considerably by the successive heatings to which it is subjected as additional layers of metal are deposited. The general type of structure of the tension bars cut from the blocks of arc fused metal will vary considerably according to the amount of refining which has taken place as well as

the relative position of the tension specimen within the block. In addition it was noticed that the columnar and coarse equiaxed crystalline condition appears to predominate with fusion at high-current densities.

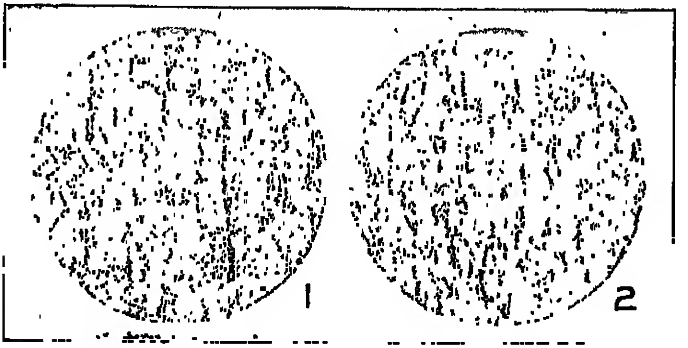


FIG. 157.—(1) "A" Electrode, $^{5}/_{32}$-in. Diameter. Annealed As Received. (2) "B" Electrode, $^{3}/_{16}$-in. Diameter. Cold-Drawn. Both $\times 100$. Picric Acid Etching.

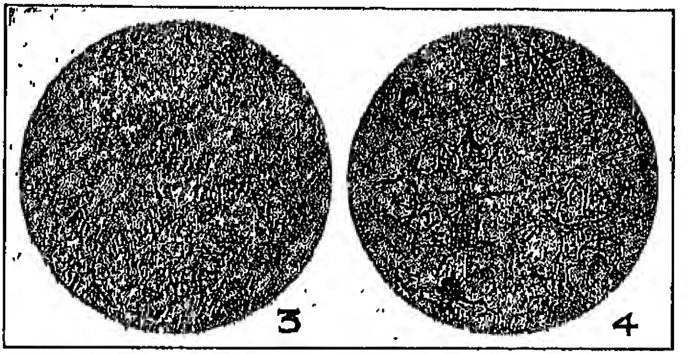


FIG. 157A.—(3) Columnar Structure of B_2. $\times 66$. Five Per Cent Picric Acid Etching. (4) Equi-axed Structure of AD_3. $\times 200$. Two per Cent Alcoholic HNO_3 Etching.

Microscopic Evidence of Unsoundness.—In all of the specimens of arc-fused metal examined microscopically there appear to be numerous tiny globules of oxide as shown in Figs. 158 to 160. A magnification of 500 diameters is usually necessary to show these inclusions. In general they appear to have

(5) Specimen AD_9. (6) Specimen A_{10} (Heated 6 hr. in Vacuo). (7) Specimen A_{10}.

FIG. 158.

"Metallic-globule" Inclusions in Arc-Fused Iron, (5) and (7) etched with 2 per cent alcoholic solution of HNO_3. (6) With 5 per cent picric acid. × 450.

no definite arrangement, but occur indiscriminately throughout the crystals of iron.

A type of unsoundness frequently found is that shown in (5), (6) and (7), Fig. 158; this will be referred to as "metallic-globule inclusions." In general these globules possess a microstructure similar to that of the surrounding metal, but are enveloped by a film, presumably of oxide. It seems probable that they are small metallic particles which were formed as a sort of spray at the tip of the electrode and which were deposited on the solidified crust surrounding the pool of molten metal directly under the arc. These solidified particles apparently are not fused in with the metal which is subsequently deposited over them—i.e., during the formation of this same layer and before any brushing of the surface occurs. By taking extreme precautions during the fusion, a great deal of this unsoundness may be avoided and the mechanical properties of the metal may be considerably improved.

Characteristic "Needles" or "Plates."—The most characteristic feature of the steel after fusion is the presence of numerous lines or needles within the crysals. The general appearance of this feature of the structure is shown in (8) to (11), Fig. 159, inclusive. The number and the distribution of these needles were found to vary greatly in the different specimens. In general, they are most abundant in the columnar and in the coarse equi-axed crystals; the finer equi-axed crystals in some specimens were found to be quite free from them, although exceptions were found to this rule. In general, a needle lies entirely within the bounds of an individual crystal. Some instances were found, however, where a needle appeared to lie across the boundary and so lie within two adjacent crystals. Several instances of this tendency have been noted in the literature on this subject. The needles have an appreciable width, and when the specimen is etched with 2 per cent alcoholic nitric acid they appear much the same as cementite—i.e., they remain uncolored, although they may appear to widen and darken if the etching is prolonged considerably. The apparent widening is evidently due to the attack of the adjacent ferrite along the boundary line between the two. The tendency of the lines to darken when etched with a hot alkaline solution of sodium picrate, as reported

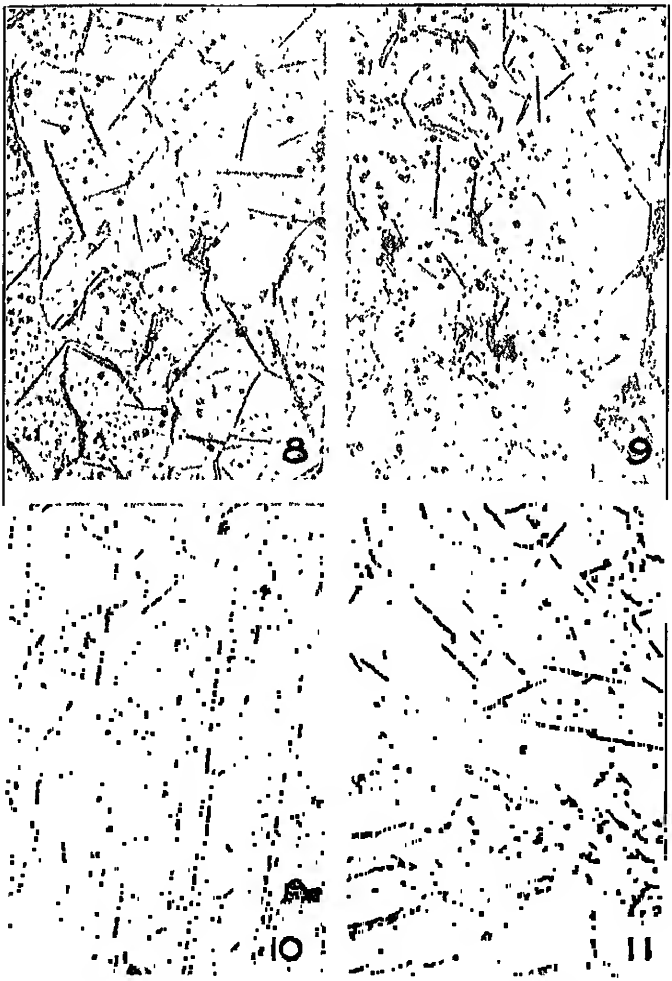


FIG. 159 (8 to 11).—Characteristic "Needles" or "Plates" × 375.

(8) BD₀ etched with 5 per cent picric acid in alcohol.

(9) Specimen BD₈ after using for thermal analysis, re-heated in vacuo to 900 deg C. four times. Picric acid etching.

(10) Same as (9) except etched in hot alkaline sodium picrate solution.

(11) Specimen of welded joint between slip plate. Additional very small needles are noted. Etching: 2 per cent HNO_3 in alcohol.

by Comstock, was confirmed; (10) illustrates the appearance when etched in this manner. The needles are sometimes found in a rectangular grouping—i.e., they form angles of 90 deg. with one another. In other cases they appear to be arranged along the octahedral planes of the crystal—i.e., at 60 deg. to one another. This is best seen in specimens which have been heated, as explained below:

In some of the specimens certain crystals showed groups of very fine short needles as in (11). The needles comprising any one group or family are usually arranged parallel to one another, but the various groups are often arranged definitely with respect to one another in the same manner as described above. Similar needles have been reported in articles by S. W. Miller.

An attempt was made by Dr. P. D. Merica to determine whether the so-called lines or needles were really of the shape of needles or of tiny plates or scales. An area was carefully located on a specimen prepared for microscopic examination, which was then ground down slightly and repolished several times. It was possible to measure the amount of metal removed during the slight grinding by observing the gradual disappearance of certain of the spherical oxide inclusions the diameter of which could be accurately measured. By slightly etching the specimen after polishing anew it was possible to follow the gradual disappearance of some of the most prominent needles and to measure the maximum "depth" of such needles. It was concluded from the series of examinations that the term "plate" is more correctly descriptive of this feature of the structure than "line" or "needle." The thickness of the plate —i.e., the width of the needle—varies from 0.0005 to 0.001 mm. and the width of the plate ("depth") may be as great as 0.005 mm. The persistence of the plates after a regrinding of the surface used for microscopical examination may be noted in some of the micrographs given by Miller. The authors are not aware, however, of any other attempt to determine the shape of these plates by actual measurements of their dimensions.

Plates Probably Due to Nitrates.—The usual explanation of the nature of these plates is that they are due to the nitrogen which is taken up by the iron during its fusion. Other sug-

gestions which have been offered previously attribute them to oxide of iron and to carbide. The suggestion concerning oxide may be dismissed with a few words. The plátes are distinctly different from oxide in their form and their behavior upon heating. It is shown later that the tiny oxide globules coalesce into larger ones upon prolonged heating in vacuo; the plates also increase in size and become much more distinct (see (32), (34) and (36), Fig. 166). In no case, however, was any inter mediate stage between the globular form and the plate pro-

FIG. 160.—(12) Specimen AD_3, Etched with 2 Per Cent Alcoholic Nitric Acid. Shows Pearlite Islands, "Needles" and Oxide Inclusions. × 750.

duced such as would be expected if both were of the same chemical nature.

Regarding the assumption that they are cementite plates, it may be said that the tendency during fusion is for the carbon to be "burned out," thus leaving an iron of low carbon content. In all the specimens, islands of pearlite (usually with cementite borders) are to be found and may easily be distinguished with certainty. The number of such islands in any specimen appears to be sufficient to account for the carbon content of the material as revealed by chemical analysis. In some cases the pearlite islands are associated with a certain type of "lines"

or "needles" such as are shown in (12), Fig. 160. These needles, however, appear distinctly different from those of the prevailing type and are usually easily distinguished from them.

The fact that the plates found in the arc-fused metal are identical in appearance and in behavior (e.g., etching) as those found in iron which has been nitrogenized is strong evidence that both are of the same nature. (13) Fig. 161 shows the appearance of the plates produced in electrolytic iron by heating it for some time in pure ammonia gas. These plates behave in the same characteristic manner when etched with hot sodium picrate as do those occurring in arc-fused

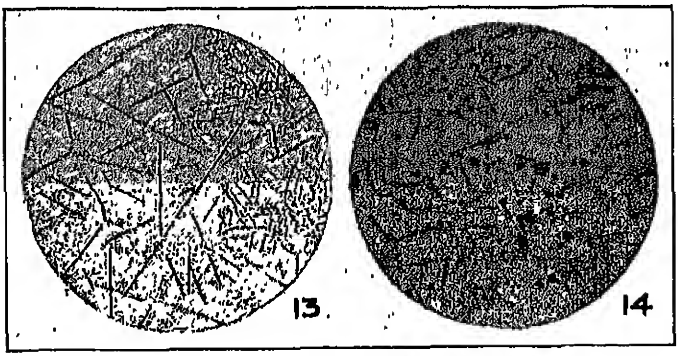
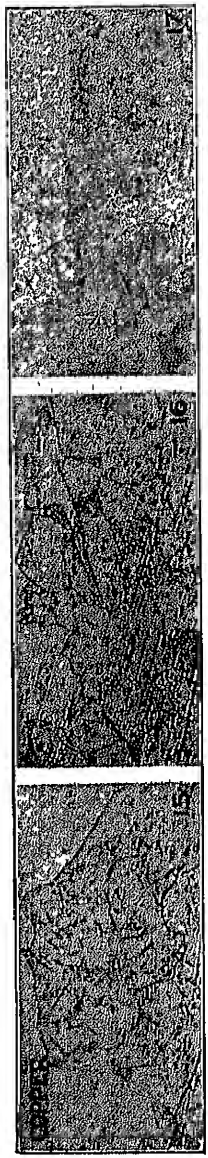


FIG. 161.—(13) Characteristic Structure of Electrolytic Iron Heated in NH_3 at 650 Deg. C. Two Types of Nitride Plates. Etched with 2 Per Cent Alcoholic HNO_3. $\times$ 375.

FIG. 161.—(14) Arc-Fused Iron Produced in CO_2 Atmosphere. Type "A," $^5/_{32}$-in. Electrodes, 150 Amperes. Etched with 5 Per Cent Picric Acid in Alcohol. $\times$ 375.

iron—i.e., they darken slightly and appear as finest rulings across the bright ferrite. The fact that the nitrogen content of the steel as shown by chemical analysis is increased by the arc-fusion also supports the view that the change which occurs in the structure is due to the nitrogen. The statement has been made by Ruder that metal fused in the absence of nitrogen —i.e., in an atmosphere of carbon dioxide or of hydrogen— does not contain any plates and hence the view that the plates are due to the nitrogen is very much strengthened. In (15), Fig. 162, the appearance of specimens prepared at the Bureau by arc fusion of electrodes of type "A" in an atmosphere of



(15) Specimen B_4. (16) Specimen B_4. (17) Specimen B_6.

FIG. 162.—Electrolytic Copper Deposit for Protection During Polishing. Etching: 2 Per Cent HNO_3 in Alcohol. $\times 280$.

carbon dioxide is shown. The microscopic examination of the fused metal shows unmistakable evidence of the presence of some plates, although they differ somewhat from those found in nitrogenized iron and in metal fused in the air by the electric arc. Evidently they are due to a different cause from the majority of those formed in the iron fused in air. For convenience, in the remainder of the discussion the "plates" will be referred to as "nitride plates."

Relation of Microstructure to the Path of Rupture.—The faces of the fracture of several of the tension specimens after testing were heavily plated electrolytically with copper so as to preserve the edges of the specimens during the polishing of the section and examined microscopically to see if the course of the path of rupture had been influenced to an appreciable extent by the microstructural features. In general, the fracture appears to be intercrystalline in type. Along the path of rupture in all of the specimens were smooth-edged hollows, many of which had evidently been occupied by the "metallic globules" referred to above, while others were gas-holes or pores. Portions of the fracture were intracrystalline and presented a jagged outline, but it cannot be stated with certainty whether the needles have influenced the break at such points or not. (16) shows the appearance of some of the fractures and illustrates that, in general, the "nitride plates" do not appear to determine to any appreciable extent the course of the path of rupture.

The behavior of the plates under deformation can best be seen in thin specimens of the metal which were bent through a considerable angle. Results of examination of welds treated in this manner have been described by Miller. Small rectangular plates of the arc-fused metal, approximately $^3/_{32}$ in. thick, were polished and etched for microscopic examination and were then bent in the vise through an angle of 20 deg. (approximate).

In (18) to (21), Fig. 163, inclusive are given micrographs illustrating the characteristic behavior of the material when subjected to bending. For moderate distortion the nitride plates influence the course of the slip-bands in much the same way that grain boundaries do—i.e., the slip-bands terminate usually on meeting one of the plates with a change of direction